PALEOGEOGRAPHIC AND TECTONIC SETTING OF AXIAL AND WESTERN METAMORPHIC FRAMEWORK ROCKS OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA

Jason B. Saleeby
California Institute of Technology
Division of Geological & Planetary Sciences 170-25
Pasadena, CA 91125

Cathy Busby
University of California
Department of Geological Sciences
Santa Barbara, CA 93106

ABSTRACT

This paper represents an update of our 1978 S.E.P.M. Mesozoic Paleogeography synthesis for the southern Sierra Nevada. We originally postulated that much of the southern Sierra Nevada pre-batholithic metamorphic framework consisted of lower Mesozoic siliciclastic, carbonate and pelitic strata with variable arc volcanic admixtures (Kings sequence). Recent syntheses, however, have attempted to minimize the importance of early Mesozoic strata in the region and to extend coherent Paleozoic terranes into the framework as the predominant protoliths. Neither lithologic correlations nor structural analysis can substantiate such a view, however, and the proposed configuration of the Paleozoic terranes is in conflict with the petrochemical zonation pattern of the Cretaceous batholith.

We present stratigraphic relations for the relatively well-preserved lower Mesozoic stratified rocks of the southern Sierra which in general supports our 1978 synthesis. As pointed out by more recent syntheses, however, we now recognize the likelihood of Paleozoic basement rocks occurring in some or many of the Kings sequence pendants. Such rocks are disparate fragments of a highly dismembered polygenetic basement composed of Paleozoic ophiolitic, Shoo Fly, miogeoclinal and possibly Antler belt rocks rather than coherent terranes or crustal blocks. The lower stratal levels of the lower Mesozoic Kings sequence appears to have formed part of a regional post-Sonoman (Triassic) marine overlap sequence above this basement complex. Dismemberment and accretion of the basement complex involved transform truncation of the southwest Cordillera and Foothills ophiolite belt emplacement prior to and coincident with Sonoman thrust tectonics. Following the establishment of a Carnian-Norian carbonate platform as part of the overlap sequence, the region subsided and became part of a regional Early Jurassic forearc to intra-arc extensional basin system with the deposition of Kings sequence turbidites and olistostromes. The basin system was destroyed by Middle and Late Jurassic thrusting.

The assertion that much of the Kings sequence is Paleozoic in age is based on the discovery of probable Eocambrian-Cambrian miogeoclinal strata in the Snow Lake pendant of the east-central Sierra Nevada (Lahren and others, 1991). These authors offer a reconstruction of the displacement of these strata as part of a large crustal block from the western Mojave region through the axial Sierra Nevada along a now cryptic fault. The bounds of the hypothetical crustal block, however, are at odds with batholithic petrochemical patterns. We propose a more conservative offset history for the Snow Lake pendant rocks which considers a broader uncertainty in the bounds of the possible source area for the rocks, and satisfies offsets of both batholithic petrochemical patterns and igneous-metamorphic assemblages of the Sierran batholithic complex.

INTRODUCTION

Metamorphic framework rocks of the axial and western zones of the southern Sierra Nevada batholith consist of steeply-dipping, NNW-trending pendants, and the highly intruded southern terminus of the western Foothills metamorphic belt. Amphibolite and hornblende hornfels facies metamorphic assemblages are widespread, and disruption of primary features is common. Early attempts to interpret these rocks in a regional stratigraphic context were offered by Bateman and Clark (1974), Saleeby and others (1978), and Saleeby (1979). Sequences of quartzite-carbonate-pelite and silicic metavolcanic rock of the axial zone pendants were referred to as the lower Mesozoic Kings sequence. Slate turbidites and chaotic chert-argillite with upper Paleozoic limestone blocks deposited on western zone ophiolitic melange were correlated to the upper Paleozoic-lower Mesozoic Calaveras Complex of the contiguous western Foothills belt to the north. Since these initial interpretive analyses, a significant body of data and a series of more sophisticated interpretations have evolved on the framework structure and stratigraphy, and on the host batholith structure and petrochemistry. In this paper we will review these new developments, and offer an updated version of our interpretation of the southern Sierra framework rocks as presented in the S.E.P.M. Mesozoic Paleogeography Volume (Saleeby and others, 1978).

New data on batholith structure and petrochemistry yield important constraints on the deformation history of the framework rocks, their crustal levels during batholith emplacement, longitudinal tectonic breaks

In Dunn, G., and McDougall, K., eds.,1993,
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within the pre-batholithic framework, and on basement relations of the framework protolith sequences. New understanding of framework rock structure and stratigraphy has arisen from detailed field mapping, rare new fossil discoveries, and major efforts in U/Pb zircon geochronology. These studies have facilitated the refinement of stratigraphic units of different age within some pendants, as well as permitting inter-pendant stratigraphic correlations and possible correlations to regions outside the southern Sierra Nevada. With these new data, regional paleogeographic and tectonic analyses have become better constrained and more sophisticated. Nevertheless, the structural and metamorphic state of the southern Sierra framework rocks has rendered significant tracts of these rocks virtually unconstrained in age and stratigraphic affinity.

Figures 1a and b are updated versions at different scales of the generalized geologic map of the southern Sierra Nevada region published in Saleeby and others (1978). The emphasis has been changed to include broad age, petrochemical and structural patterns of the batholith as well as framework rock stratigraphy. Figures 2 through 4 show critical structural and stratigraphic relations for the better preserved and more thoroughly understood sequences in a number of pendants. Much of our discussion will focus on these sequences. We will begin our discussion with broad patterns observed within the host batholith, and then focus on framework stratigraphy.

BATHOLITH REGIONAL STRUCTURE AND PETROCHEMISTRY

The southern Sierra Nevada batholith exhibits a number of distinct regional patterns in age, structure and petrochemistry which help constrain the pre-batholith framework geology. These constraints are particularly useful in evaluating the possible distribution of pre-batholithic tectonic breaks that involved juxtaposition of contrasting basement terranes. An overview of these patterns will help pose some of the major tectonic and paleogeographic problems in interpreting the pre-batholithic tectonic framework and stratigraphy.

Age Patterns

Much of the southern Sierra Nevada batholith is Cretaceous in age, with a transverse zonation pattern of voluminous plutonism having commenced in the west at ~125 Ma and progressed eastward through time to an ~85 Ma culmination (Evernden and Kistler, 1972; Saleeby and Sharp, 1980; Stern and others, 1981; Chen and Moore, 1982). Regionally, the Cretaceous composite batholith trends ~N15°W and crosses a Jurassic plutonic belt that trends ~N30W (Fig. 1a). The Jurassic belt is well-expressed within and along the eastern margin of the western Foothills metamorphic belt, as well as in the Kern plateau area of the southeastern Sierra Nevada (Evernden and Kistler, 1972; Snoke and others, 1982; Kistler, 1990; Saleeby and others, 1990; Dunne and others, 1991). Igneous ages fall between ~170 and 148 Ma with an apparent lull between 160 and 152 Ma. Only three small clusters of Jurassic plutons have been recognized within the Cretaceous batholith, between the western Foothills belt and the Kern plateau area (Chen and Moore, 1972; J.G. Moore and Saleeby, unpub. data).

Petrochemical Patterns

The Cretaceous Sierra Nevada batholith exhibits a transverse zonation pattern in petrochemistry which mimics the age zonation pattern. The petrochemical zonation reflects contributions from different deep crustal materials to the batholithic magma systems. A first order observation is that gabbroic to tonalitic associations are widespread along the western zone of the batholith, whereas granodioritic to granitic associations greatly dominate the eastern zone (Moore, 1959; Saleeby, 1981). This pattern is paralleled by an isotopic zonation pattern whereby batholithic rocks along the western zone more closely record a depleted mantle source component, whereas those to the east reflect substantial components of sialic North America (Kistler and Peterman, 1973; Saleeby and Chen, 1978; DePaolo, 1981; Saleeby and others, 1986; Kistler, 1990, this volume; Knott and others, 1990; Pickett and Saleeby, 1990; Chen and Tilton, 1991). The zonation pattern in a broad context can be attributed to a pre-batholithic lithospheric boundary along the axial to western Sierra Nevada with oceanic or ophiolitic basement to the west and North American sial to the east.

Coupling of the Sr-Nd-Pb radiogenic as well as stable O isotopic data (referenced above) with the batholithic mineral chemistry data of Ague and Brimhall (1988a) constrains a model for the relation between pre-batholith lithospheric structure and the related batholithic petrochemical variation patterns (Kistler, 1990; Saleeby and Busby-Spera, 1992). A fundamental largely cryptic lithospheric boundary (CLB) runs along the axis of the southern Sierra Nevada. Pre-batholithic deep crustal rocks to the east of the CLB were hosted by North American continental lithosphere. To the west deep crustal rocks consisted of accreted Paleozoic oceanic lithosphere overlain by a wedge of pelite-rich sedimentary material derived primarily from North American sial; this wedge thinned to effectively zero along the western Foothills. The CLB corresponds to a distinct framework rock change in the Kern Plateau region (Fig. 1; Kistler, 1990; Dunne and Suczek, 1991; Saleeby and Busby-Spera, 1992). Its continuation to the north is more speculative and will be discussed below as well as a more thorough treatment of the Kern Plateau relations. Additional dextral sense tectonic breaks oriented along the trend of the batholith are suggested by sharp offsets in initial $^{87}Sr/^{86}Sr$ (Sr_i) isopleth patterns (Kistler and Peterman, 1973, 1978; Saleeby and others, 1986; Kistler, this volume). Three such breaks were originally defined as intrabatholithic breaks 1, 2 and 3 (Saleeby and others, 1986). Finer resolution of the defining features has led to the abandonment of number 1 and better documentation of 2 and 3 (Kistler, this volume). Below and on Figures 1a and b we refer to these as the axial (AIB) and eastern (EIB) intrabatholithic breaks respectively. The AIB appears to truncate and offset the CLB at a low angle of discordance within the southern Sierra region (Fig. 1a).

Regional Batholith Structure

A number of regional structural patterns in the Cretaceous Sierra Nevada batholith are pertinent to the structural, stratigraphic and paleogeographic analysis of the framework rocks. Most fundamental is a gross longitudinal depth zonation pattern whereby shallow to surface-level batholithic and batholith ejecta metavolcanic rocks remain in the central Sierra region, centered about latitude 37°30'N, and progressively deeper batholithic rocks are exposed southward to ~25 km depth-levels in the Tehachapi gneiss complex (Fig. 1a; Saleeby and others, 1986; Ague and Brimhall, 1988b; Saleeby, 1990a; Pickett and Saleeby, in press). The depth zonation pattern is most clearly developed for igneous-metamorphic assemblages of ~100 ±5 Ma. Another possible, yet poorly explored, fundamental pattern is a longitudinal dextral stepping pattern in the loci of large volume silicic pluton emplacement generalized as the approximate back edge of mid- and Late Cretaceous magmatic loci on Figure 1a. This pattern, coupled with the existence of Cretaceous-age dextral ductile shear zones oriented along the axis of the batholith, poses the possibility that the Cretaceous batholith was emplaced in a dextral transtensional-transpressional tectonic regime (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1989; Saleeby, 1991, 1992a; Tikoff and Teyssier, 19921). We will briefly explore the pertinent aspects of these regional structural patterns below.

Some Aspects of the Depth Zonation Pattern

Recognition of the depth zonation of the batholith in conjunction with structural and geochronologic studies has shed light on batholith emplacement dynamics which are pertinent to the structural and stratigraphic analysis of the metamorphic framework rocks (Saleeby and Busby-Spera, 1986; Saleeby and others, 1987; Saleeby, 1990a). The framework rocks occur primarily as grossly concordant steeply-dipping screens between different plutons, or different phases of large composite plutons. A majority of the plutons are elongate in a NNW direction, and thus the screens roughly strike in this direction. The screens typically have steep concordant foliations with strong to moderate down-dip constrictional fabrics. This structural relation is shown to have arisen from downward synmetamorphic ductile return flow during the rise of the more voluminous silicic magma bodies (Saleeby 1990a). A first-order structural consequence was the transposition of most earlier structures, primary and tectonic, into the regional trend of the screens and plutons. Many of the screens are penetratively schistose to modestly gneissose throughout, whereas some of the high level ones contain significant domains of hornfels, and locally prebatholithic metamorphic textures. In our stratigraphic discussions below we will refer to the screens as pendants based on prior nomenclature; actual "roof" pendants are rare in the southern Sierra.

There are two important structural-stratigraphic consequences of the return flow structure: 1) A number of large enclaves of silicic metavolcanic rock that are essentially coeval to the invading plutons (within 2 to 5 m.y. of age) were trapped and transported downward locally to depths in excess of 10 km. Notable examples include the Boyden Cave, Sequoia Park, Tule River and Isabella pendants (Fig. 1b). Transposition of the primary volcanic structures, and underlying unconformities, hypabyssal complexes or tectonic breaks, along with the transposition of the older mainly metasedimentary sequences obscured major age gaps which led to erroneous interpretations of these and other pendants as lower Mesozoic metasedimentary <u>and</u> metavolcanic sequences (Bateman and Clark, 1974; Saleeby and others, 1978). The amount of significantly "prebatholithic" metavolcanic rock in the axial southern Sierra framework is much less than previously believed. 2) As deeper levels of the batholith and framework are traversed, progressively more pelitic and psammitic members of the metasedimentary protolith sequence(s) were melted and mixed into the batholithic magma systems. This pattern is particularly prevalent from the Lake Isabella area southward. High-grade metaquartzite, marble and calcsilicate rock represent the refractory phases of these ultrametamorphic assemblages, and in the southernmost Sierra the original stratigraphic and/or structural sequences of these rocks may have been drastically changed from their protolith sequences by selective removal of pelitic-psammitic members.

Synbatholithic Dextral Shear

Initial Sr isotopic data on the Sierra Nevada batholith reveal a radiogenic maxima centered over the axial zone of the batholith that is also paralleled by Pb and Nd isotopic data (Kistler and Peterman, 1973; DePaolo, 1982; Kistler, 1990, this volume; Chen and Tilton, 1991). The radiogenic high domain terminates northward as a northwest trending promontory at ~39° latitude which is ~125 km north of Figure 1a (Kistler, this volume), and appears to track southward in continuity with a broad radiogenic high region which underlies much of the Mojave Desert (Kistler, 1990). This pattern has been interpreted as resulting from the intrabatholithic breaks (Fig. 1a) displacing North American sialic basement northward into the axial Sierra region, thereby supplying this material as a source component for the Cretaceous magma systems (Kistler and Peterman, 1973; Saleeby

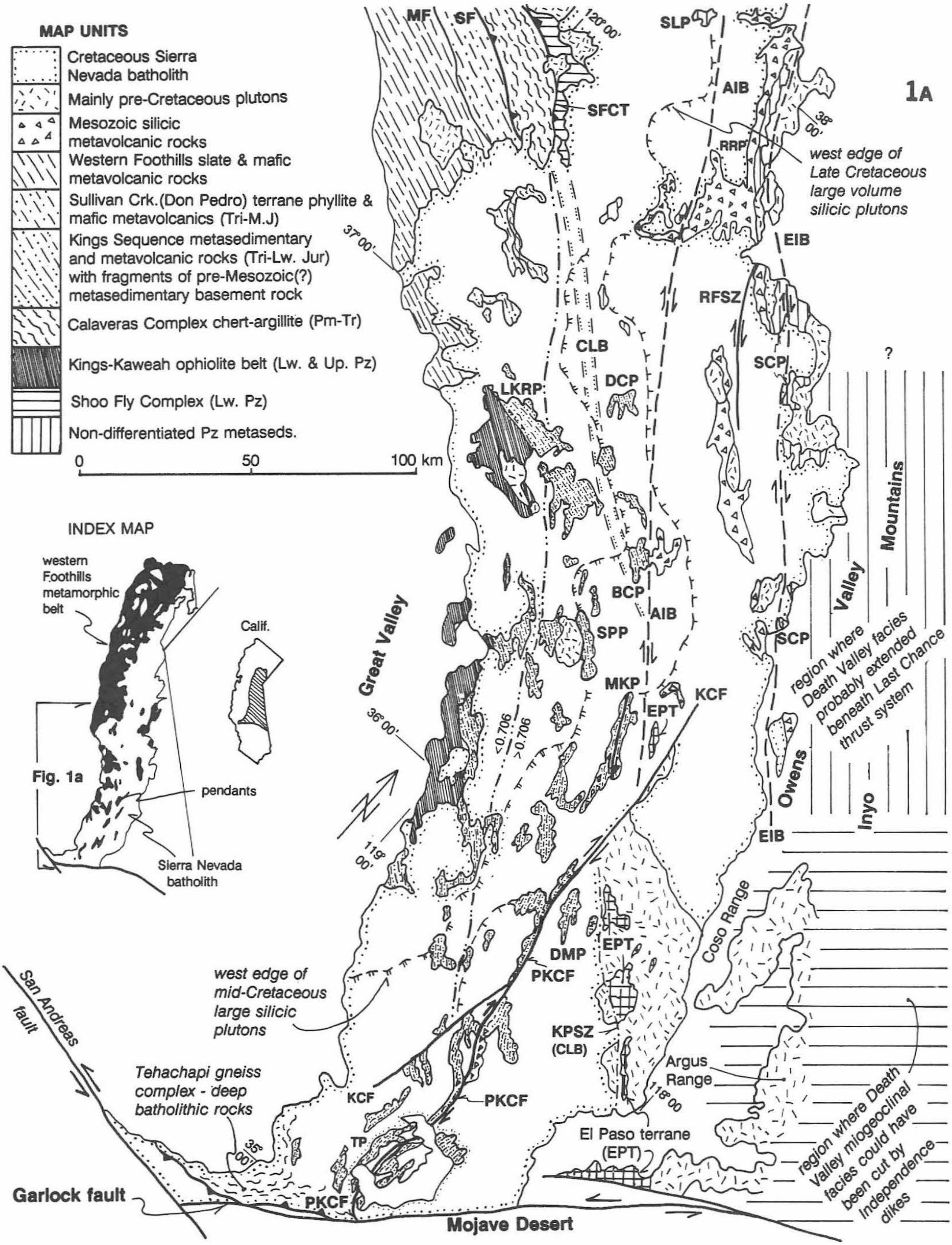


Figure 1*a*. Tectonic map of southern Sierra Nevada region showing major structural features of batholith and metamorphic framework (references given in text). See Figure 1*b* for abbreviations.

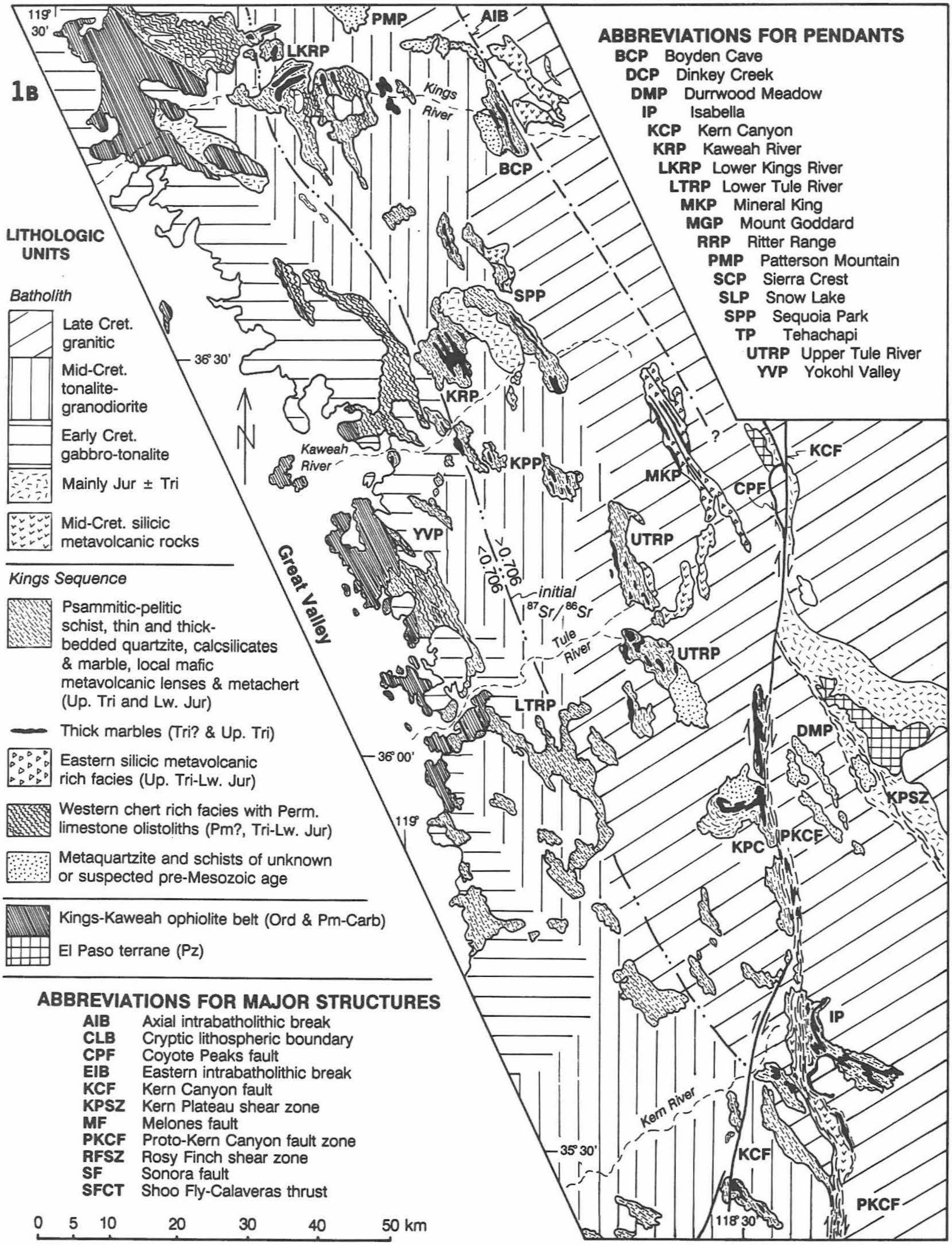


Figure 1*b*. Generalized map of axial and southern Sierra Nevada showing main metamorphic pendants discussed in text and selected features from cross-cutting batholith (modified from Saleeby and others, 1978; additional references in text).

and others, 1986; Kistler, 1990, this volume).

Until recently, direct geologic constraints on the nature and timing of dextral offsets along the axial Sierra have been sparse. There are now two strong lines of geologic evidence to support such an offset pattern. 1) A stratigraphic correlation between framework rocks of the Snow Lake pendant (Fig. 1a), and Eocambrian-Cambrian strata of the Death Valley facies of the miogeocline indicates between 200 and 400 km of dextral offset in Early to mid-Cretaceous time (Lahren and others, 1990; and discussion below). 2) Dextral-sense, synbatholithic ductile shear zones (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1989; Saleeby, 1991, 1992a; Tikoff and Teyssier, 1992) coupled with the longitudinal dextral-stepping pattern in the loci of pluton emplacement noted above support substantial dextral drag along the batholith axis during mid- to Late Cretaceous dextral sense oblique subduction (Engebretson and others, 1985).

Finally, another important consequence of Cretaceous dextral shear is the production of a major belt of metamorphic tectonites within the framework rocks of the southern Sierra Nevada. This belt has been traced for ~125 km (Fig. 1a), and is termed the proto-Kern Canyon fault zone (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1989; Gazis and Saleeby, 1991; Saleeby, 1991, 1992; Wood and others, 1993). It constitutes the most regionally extensive dextral ductile shear zone currently recognized in the Sierra Nevada, and in the framework rocks it completely transposes all earlier structural features including high-grade synbatholithic structures.

METAMORPHIC FRAMEWORK ROCKS

This paper focuses on metamorphic framework rocks between latitude 35°30' and 37°00'N, and west of longitude 118°15'W (Fig.1b). Three belts of metamorphic rock occur in this region. 1) To the east are sparsely fossiliferous lower Mesozoic rocks of the Kings sequence. Bateman and Clark (1974) defined the Kings sequence as lower Mesozoic quartz-rich metasedimentary and silicic metavolcanic rocks in the northern part of the region; Saleeby and others (1978) later extended the Kings sequence to the southern end of the Sierra Nevada. Sparse fossils are Late Triassic and Early Jurassic in age (Christensen, 1963; Jones and Moore, 1972; Moore and Marks, 1972; Saleeby and others, 1978; Busby-Spera, 1983). Schweickert and Lahren (1991) have suggested that much of the Kings sequence consists of various Eocambrian to Paleozoic quartz-rich units that can be correlated with major terranes or stratigraphic sections outside the study area, and that the term "Kings sequence" should be abandoned. We will address this question below. Stratigraphic relations for the Kings sequence are best preserved in the Mineral King, Boyden Cave, and Isabella pendants (Fig. 1b). 2) The Kings-Kaweah ophiolite belt and depositionally overlying metasedimentary and metavolcanic rocks occur along the southwestern edge of the study area; the overlying rocks have similarities to both western Foothills belt rocks to the north and basinal facies Kings sequence rocks to the east (Saleeby, 1977, 1978, 1979; Saleeby and others, 1978). The Kings-Kaweah ophiolite belt contains two ocean floor igneous phases that are Ordovician and Permo-Carboniferous in age; elements of the overlying sedimentary-volcanic rocks are possibly as old as Permian and possibly as young as Middle Jurassic (Saleeby and Sharp, 1980; Saleeby, 1982, 1990, 1992b). 3) Metamorphic framework rocks constituting highly deformed pendants of the lower Kings River and much of the Kaweah and Tule River drainages are poorly constrained in age. The age and petrotectonic setting of this belt of pendants, which we consider also to be primarily lower Mesozoic Kings sequence, may be interpreted by lithologic comparisons to fossiliferous Kings sequence strata to the east and strata overlying the ophiolite belt to the west.

Distinct belts of Mesozoic metavolcanic pendants and Paleozoic metasedimentary pendants lie east of the Kings sequence pendants (Fig. 1a). In the north, Mesozoic silicic metavolcanic rocks with subordinate metasedimentary rocks occur in the Mount Goddard and Sierra crest pendants (Tobisch and others, 1986; Saleeby and others, 1990). Framework rocks of the Kern Plateau region consist of continental rise and slope strata, and overlying volcanic arc strata that are similar to Ordovician to Mississippian and overlying Early Permian strata of the El Paso terrane which can be correlated farther to the southeast beyond the southern Sierra (Dunne and Suczek, 1991).

In the discussion that follows, we will emphasize the better constrained pendants of Kings sequence rocks, in terms of age and lithologic character, and then progress to the more enigmatic rocks.

Mineral King Pendant

General

The Mineral King pendant is a major focus of our discussion because: 1) It possesses the most intact stratigraphy and protolith geology of all the pendants in the southern Sierra Nevada; 2) It has a number of fossil localities and has yielded some valuable U/Pb zircon dates; 3) It has the greatest abundance of early Mesozoic metavolcanic rock of any southern Sierra pendants; and 4) Major pre- and early batholithic tectonic boundaries have been suggested to pass through the pendant (Kistler, 1990, this volume; Schweickert and Lahren, 1991). A generalized geologic map and stratigraphic columns are given for the Mineral King pendant in Figure 2.

Lower Mesozoic marine metasedimentary and metavolcanic rocks are interstratified in subequal proportions in the Mineral King pendant. These strata form a vertically-dipping, east-facing homocline that is locally tightly folded or faulted (Busby-Spera, 1983, 1984a; Busby-Spera and Saleeby, 1987). Cleavage, foliation, faults and shear zones are subparallel to the NNW-striking bedding and metamorphic grade is mainly upper greenschist, notably lower than most Kings sequence pendants. Christensen (1963) interpreted the lithologic layering within the pendant as a transposition foliation with no stratigraphic significance, and that the pendant is only superficially homoclinal. His interpretations only apply to the marbles and some of the calcsilicates, however (Busby-Spera and Saleeby, 1987). Sedimentary facing data, not used in Christensen's study, show that all of the metavolcanic strata, and many of the metasedimentary strata are not folded. In those localities where reversals in sedimentary facing direction do occur, fold hinges are well-preserved in all but the most incompetent units. Furthermore, many of the metasedimentary and metavolcanic map units show systematic vertical and lateral sedimentary facies sequences that prove there is intact stratigraphy within much of the pendant (Busby-Spera, 1983, 1984a,b, 1985, 1986; Busby-Spera and Saleeby, 1987; Kokelaar and Busby, 1992).

Two significant pre- or early batholithic faults are named on Figure 2. The Farewell fault is a zone of brittle shear, 1-20 m wide, that divides the pendant longitudinally (Busby-Spera, 1983, 1984a; Busby-Spera and Saleeby, 1987). The fault lies completely within one map unit (slate), so offset is probably not of great magnitude. Slaty cleavage is folded about steeply plunging axes within the fault zone, with a pervasive sense of asymmetry indicative of dextral shear. The Empire fault is a zone of ductile shear in the northeast part of the pendant that is responsible for the northward termination of the SM_2 metasedimentary and A_3 metavolcanic map units. A mylonitized dacite which occurs as a sliver along the Empire fault has yielded a ~240 Ma U-Pb zircon age (Busby-Spera, 1983; Busby-Spera and Saleeby, 1987). Kistler (1990) used strontium isotope data on this fault sliver to correlate it with a NW-trending belt of ~240 Ma plutons in the El Paso Mountains and adjacent Kern plateau region whose eastern margins are terminated by the CLB (Fig. 1a). He proposed that the CLB coincides with the Empire fault thus making the fault a major lithospheric boundary. We suggest below, however, that the fundamental nature of the CLB predates deposition of the protolith sequence and that the Empire fault may record local remobilization of the CLB. We now turn to the protolith stratigraphy.

Protolith Stratigraphy

The twenty-two nonintrusive map units shown in Figure 2 and Table 1, and are named by dominant rock type, using the protolith name except for the most metamorphosed or deformed calcsilicate, marble and slate units. The map units are numbered by inferred stratigraphic order. In this section, we summarize the stratigraphic evolution of the Mineral King pendant after the more detailed descriptions of Busby-Spera (1983, 1984a,b, 1985, 1986), Busby-Spera and Saleeby (1987), and Kokelaar and Busby (1992).

The base of the section consists of calcsilicates and marbles (CS_{1-3} and M_1) with interstratified laterally discontinuous volcanic rocks, including the R_0 rhyolite ash-flow tuff and the A_0 andesite lava flows and/or hypabyssal intrusions. Calcsilicate map units at Mineral King record periods of local volcanic and tectonic quiescence, when distal ashes and silts settled through water depths below wave base onto a lime mud substrate. Thin-bedded pure limestones formed when no detritus or ash reached the carbonate substrate. The basal calcsilicates and marbles are conformably overlain by the breccia-sandstone units (Br) in the southern half of the roof pendant, and this unit in turn forms the walls and floor of the Vandever Mountain caldera, which is filled by the R_1 rhyolite ash-flow tuff. The breccia-sandstone unit is interpreted as a deep marine debris apron formed of material shed from a submarine fault scarp. Fault-talus breccias accumulated at the foot of the normal fault scarp, which exposed calcsilicates and carbonates in its face (map units $CS_{2,3}$ and M_1); these pass distally (southward) into turbidites. This normal fault acted as a conduit for eruption of small-volume pyroclastic flows precursory to the caldera-forming eruption of map unit R_1.

Rhyolite ash-flow tuff unit R_1, referred to as the Vandever Mountain tuff, fills a caldera subsidence structure about 8 km across and 500 m deep. It is dominantly a massive, nonsorted tuff that welded in a deep-marine environment, although its uppermost part passes gradationally into thin-bedded, well-sorted subaqueous fallout tuff and, ultimately, deep-marine shales and turbidites of the overlying slate map unit (Sl). The slate map unit runs the length of the Mineral King roof pendant, and represents an anoxic starved deep marine basin that occasionally received minor turbidity current incursions and subaqueous fallout of ash. In the southern half of the pendant, the slate unit passes gradationally upward into the overlying turbidite unit (map unit T) through a 100 m thick upward-coarsening and upward-thickening sequence of beds inferred to represent progradation of fan-fringe and outer fan deposits into the basin. The 480 m thick turbidite unit is interpreted to be a progradational submarine fan sequence that includes outer fan lobe deposits in its lower part and middle fan channel deposits in its upper part (Bullfrog fan of Busby-Spera, 1985). It has a high overall sandstone to shale ratio and shares features in common with other sand-rich submarine fans described in the literature (Busby-Spera, 1985). The sand-sized material in the turbidite unit was provided by downslope reworking of rhyolite pyroclastic debris from an active volcano. At the same stratigraphic level in the northern third of the pendant lies an

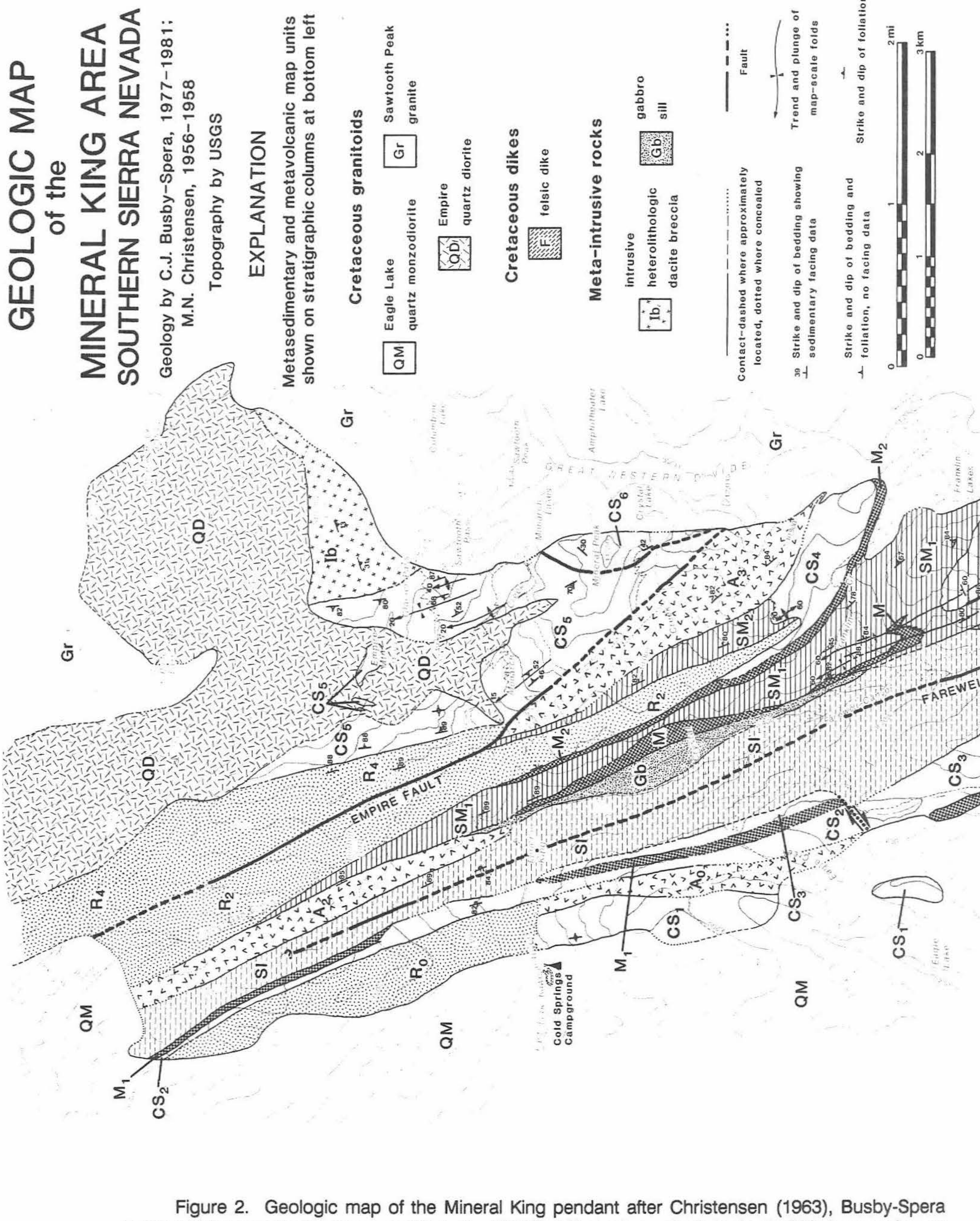
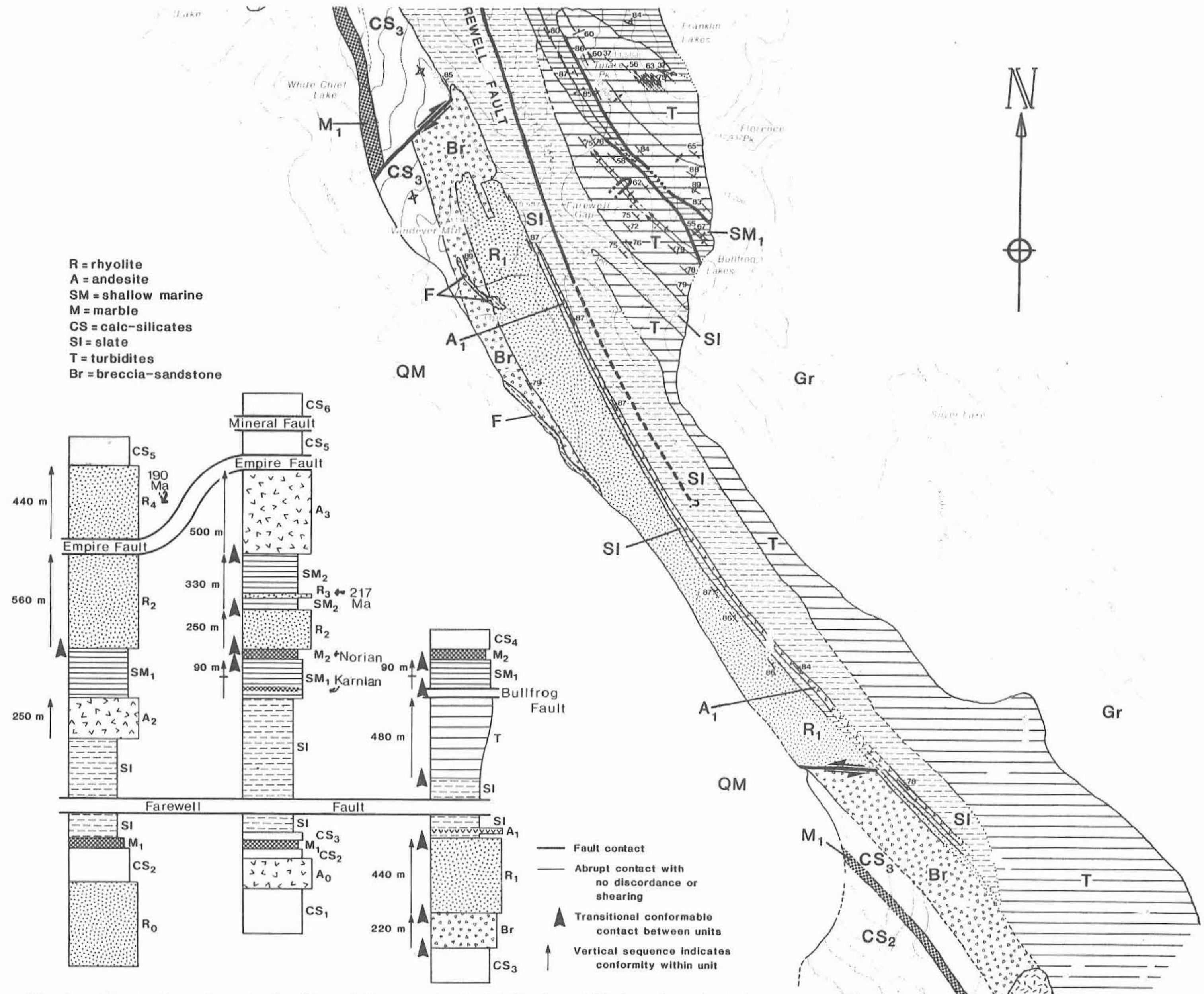


Figure 2. Geologic map of the Mineral King pendant after Christensen (1963), Busby-Spera (1983, 1984a) and Busby-Spera and Saleeby (1987). Lithologic symbols for batholithic host rocks are given in upper right corner. Lithologic symbols for metasedimentary and metavolcanic pendant rocks

are given in diagrammatic stratigraphic columns in lower left corner. Symbols for stratigraphic units and protolith descriptions are given in Table 1.



Stratigraphic sections through the Mineral King pendant at latitudes of Timber Gap, Crystal Creek, and Vandever Mountain (left, center, and right columns, respectively). Bases of columns are at west side of pendant, tops at east.

Table 1. Protolith Description of Map Units in the Mineral King Pendant

METAVOLCANIC PROTOLITHS

Rhyolite ash-flow tuffs (minor tuffs, lahars, sills, lava flows)

R_4	Massive ash-flow tuff. Laminated tuffs form interbeds in southern part of sheet and overlie it (along the east margin). Sparse volcanic lithic fragments. Phenocrysts of quartz, potassium feldspar, plagioclase.
R_3	Thin (6 m) massive ash-flow tuff, with quartz and plagioclase phenocrysts. No lithic fragments.
R_2	Massive ash-flow tuff, pumice textures well-preserved. Laminated tuff and lahars form interbeds in southern (distal) part of sheet and overlie it (along the east margin). Phenocrysts of quartz, potassium feldspar, plagioclase. 3-40% volcanic lithic fragments. Small basalt lava flow. Thin sills of flow-banded rhyolite.
R_1	Massive ash-flow tuff, with bedded lapilli tuffs and tuffs and massive lahars at top (eastern margin) of sheet. Compositionally zoned, with total quartz and ratio of potassium feldspar to plagioclase decreasing upward. 2-15% volcanic lithic fragments.
R_0	Massive ash-flow tuff; thin-bedded crystal tuffs and lapilli tuffs along eastern (upper?) margin. Quartzofeldspathic lenticles (relict pumice) in a relatively coarsely-recrystallized matrix of quartz, microcline and sericite. Phenocrysts of quartz and feldspar. Lithic fragments very rare.

Andesite pyroclastics and lavas (lesser lahars, sandstones, sills and dikes)

A_3	Hyaloclastic lava flows and massive tuff breccias pass outward and upward into bedded lapilli tuffs overlain by laminated tuffs. Monolithologic. Phenocrysts of plagioclase, and hornblende. Sills, dikes.
A_2	Amygdaloidal lavas and laminated tuffs interfinger with tuff breccias, tuff turbidites, lahars. Phenocrysts of plagioclase and minor uralitized mafics. Thin (<5m thick) rhyolite ash-flow tuff at base laterally removed by soft-sediment slumps.
A_1	Monolithologic tuff breccia with phenocrysts of plagioclase, hornblende locally replaced by biotite. Consist of two laterally extensive (>7 km) thin (15m and 30m) pyroclastic flows separated by 15m of pyritic slate, which also encloses it (map unit S1). Minor lenticular pebbly sandstone turbidites and calcareous debris flows.
A_0	Very poorly exposed lava flows and/or hypabyssal intrusions with plagioclase phenocrysts.

METASEDIMENTARY PROTOLITHS

Shallow Marine:

Thin to very thick-bedded sandstones, siltstones, and marbles, with planar lamination, wave ripple cross-lamination, hummocky and trough cross-lamination. Relict crinoids and coquinoids. Minor conglomerates and tuffs.

SM_1	Marbles, laminated to massive calcareous siltstones and silicic tuffs. Lesser parallel-laminated to trough cross-laminated sandstones with gravel lags.
M_2	Marble with rare relict sedimentary structures including crinoids, brachiopods and bivalves, and thin, tightly-folded beds of wave ripple cross-laminated and parallel-laminated siltstones.
SM_2	Lower part of section tightly folded, with marbles, siltstones and thin- to medium-bedded sandstones. Parallel-lamination, grading, wave ripple cross-lamination, penecontemporaneous deformation structures (ball and pillow, load-casted ripples, intraclastic breccias, small slump folds); interstratified beds with Bouma divisions a,b,c, and scoured bases, flame structures, dish structures.
	Note: Marble unit M_1 is too recrystallized and deformed to show primary sedimentary structures.

Deep Marine:

Generally fine-grained parallel-laminated clastic and calcareous rocks, or sandstones with Bouma divisions.

T	Turbidites - thin to very thick-bedded volcanic lithic sandstones with euhedral crystals of feldspar and quartz. Minor tuffs and lapilli tuffs. Lahars at top of section. Bouma sequences present, but thick beds are commonly massive or crudely laminated. Lower half of section has laterally continuous sandstones forming upward thickening and coarsening sequences of beds. Upper half of section contains channelized sandstones with upward fining and thinning sequences or amalgamated pebbly sandstones.
SL	Slates - commonly pyritic; contain thin-bedded volcanic lithic sandstones with Bouma divisions c,d,e. Minor tuffs, lapilli tuffs, marbles.
Br	Breccias and sandstones. This unit forms a wedge that fines and thins distally (north to south) from breccias, siltstones and lesser pyroclastic flows to turbidites, siltstones and laminated tuffs. Breccias contain angular fragments of carbonate, calcsilicate and fine-grained tuff.
CS	Calcsilicates - metacalcareous siltstones, fine-grained sandstones and tuffs. Marbles common. Parallel lamination and faint grading locally preserved. Map unit CS_5 contains metacalcareous quartz sandstones with lesser thick beds of lapilli tuff.

andesite map unit (A_2) interpreted to represent a small stratocone (Timber Gap andesite of Busby-Spera, 1986). The lower of two shallow marine units in the Mineral King pendant (SM_1) is in fault contact with the turbidite unit at the southernmost end of the pendant, but it conformably overlies the turbidite unit along most of its length, and also overlies the A_2 andesite unit.

The lower shallow marine unit (SM_1) consists of a lower folded interval of outer shelf deposits, and an upper homoclinal section that forms a 90 m thick progradational outer shelf to nearshore sequence. This is overlain along much of its length by a thick fossiliferous marble (M_2) inferred to have been deposited in an outer shelf environment. The R_2 rhyolite ash-flow tuff (Monarch tuff of Busby-Spera, 1986) overlies this marble in gradational, interfingering contact. This ash-flow tuff thickens dramatically (from 0 to 600 meters) from south to north, and is inferred to represent the fill of a trap-door caldera (Busby-Spera, 1984b). It in turn is overlain by the upper shallow marine unit (SM_2), which appears to form an up to 300 m thick homoclinal section. The upper shallow marine unit differs from the lower shallow marine unit in two important ways. First, it is sandwiched between two major volcanic units, and contains proximal volcanic rocks, including rhyolite ash-flow tuff unit R_3, which is too thin to show on the map but has yielded Late Triassic U-Pb zircon ages. Second, instead of showing a simple outer shelf to nearshore progradational sequence, rapid fluctuations in relative sea level are recorded. Thus, local volcanic quiescence was accompanied by steady subsidence as SM_1 accumulated, and local volcanic activity was accompanied by tectonic instability during deposition of SM_2. Continued subsidence is recorded in the deposits of the overlying map unit A_3 (Cobalt Lake andesite stratocone of Busby-Spera, 1986), which accumulated in deep water.

Rhyolite ash-flow tuff unit R_4 is in fault contact with the R_2 tuff and the A_3 andesite along the Empire fault. The Rhyolite ash flow yields a younger U-Pb zircon age (Early Jurassic). It passes gradationally upward into the youngest calcsilicate unit, CS_4, that was derived from calcareous quartz arenite.

Fossil and Radiometric Age Controls

There are few age controls on the stratigraphy at Mineral King, because metamorphism has resulted in recrystallization and deformation of fossils, as well as post-crystallization disturbance in many of the U-Pb zircon samples from metavolcanic units. All of the age diagnostic fossils have come from metacalcareous siltstones (now schists) associated with marbles. Fossils in marbles or metacalcareous sandstones are too recrystallized or deformed to be age diagnostic. Only two out of eight samples from metavolcanic units have yielded concordant U-Pb zircon dates. U/Pb zircon ages from the unmetamorphosed plutons that surround the pendant, in contrast, are all concordant.

Fossil and radiometric age data indicate that the upper and lower shallow marine unit (SM_1 and SM_2) and intercalated metavolcanic rocks (R_2 and R_3) are Late Triassic in age. Christensen (1959) reported Carnian and Norian marine fossil localities within the lower shallow marine unit (SM_1). Unit M_2, a laterally continuous marble interpreted to lie in conformable contact above the lower shallow marine unit and below map unit R_2, has yielded a collection of brachiopods and bivalves at a locality in Crystal Creek (provided to us by amateur collectors, Dr. and Mrs. Koch). This collection is not age-diagnostic, but "resembles a Mineral King collection from last century housed at the USGS that is early to middle Norian in age" (N. Silberling and D. Jones, written comm.). The ash-flow tuff that conformably overlies the fossil-bearing marble, map unit R_2, has yielded discordant U-Pb zircon dates from two different samples, but a concordant zircon date of 217 Ma has been determined for an ash-flow tuff within the conformably overlying shallow marine unit (R_3, in unit SM_2; Busby-Spera, 1983). This date is middle Norian, according to the DNAG (1983) Geologic time Scale.

The 190 Ma U-Pb zircon age for the R_4 ash-flow tuff that lies near the eastern margin of the pendant supports the interpretation that the east-facing section is progressively younger from west to east, although direct age controls are lacking for the western (older?) half of the pendant. U-Pb zircon dates from map units R_0, R_1, R_2 and A_2 are all highly discordant, probably due to minor inheritance followed by lead loss (Busby-Spera, 1983).

Both Late Triassic and Early Jurassic fossils have been recovered from argillitic fault slivers along the pair of faults that trend NNW from Bullfrog Lakes. The collection includes the Early Jurassic fossil Weyla, which also occurs in the Ritter Range and Lake Isabella pendants to the north and south, respectively (Fiske and Tobisch, 1978; Saleeby and others, 1978). Dip-slip movement, inferred for this fault on stratigraphic grounds, probably resulted in downward displacement of Jurassic fault slivers from higher parts of the section.

Hypothetical Basement Rocks and Major Structures Along the Western Margin of the Pendant

Schweickert and Lahren (1991) examined a marble along the western edge of the Mineral King pendant in contact with Cretaceous granitic rocks, and noted that it was coarsely crystalline, strongly foliated, and that impure layers within it formed tectonic lenses and rootless folds. Because rocks east of this marble did not appear as deformed, they inferred that the marble marks a major shear zone, perhaps the Mojave-Snow Lake fault, and that the marble itself could be a small slice of the miogeoclinal strata of the Snow Lake block. Deformation fabrics, however, are inhomogeneously developed throughout the pendant (Busby-Spera and Saleeby, 1987). Lithic fragments in metasedimentary and metavolcanic breccias and conglomerates are not pervasively flattened, and metasandstones, although in places tightly folded, commonly show little or no flattening of primary sedimentary structures. In marked contrast, marbles at all stratigraphic levels are pervasively foliated (Busby-Spera and Saleeby, 1987). Christensen (1963) noted that the thicker marble bodies tend to be coarser grained and more strongly foliated, with more intricate folding, than the thinner marbles. The marble that Schweickert and Lahren (1991) examined (M_1 of Figure 2) is one of the thicker bodies, and is not any more deformed or in any other way dissimilar to the other thick marbles throughout the pendant, which bear Triassic fossils (M_2 of Figure 2) and/or are interstratified with Triassic and Jurassic volcanic rocks (Busby-Spera, 1983; Busby-Spear and Saleeby, 1987). There is thus no compelling evidence for the Mojave-Snow Lake fault, nor for miogeoclinal basement, within the Mineral King pendant.

Schweickert and Lahren (1991) also used the 1905 Knopf and Thelen description of quartzite in the southern tail of the Mineral King pendant to suggest that miogeoclinal basement of the Snow Lake block is present there as well. We have examined these outcrops, which are best characterized as siliceous hornfels, calcsilicate and marble. The protolith for the siliceous hornfels is a very impure sandstone, with up to 25% metamorphic biotite. Miogeoclinal-like quartz arenites are not present. The stratigraphic affinity of these rocks is unknown, although similar lower Mesozoic rocks are present in the area of Figure 2.

Schweickert and Lahren (1991) also proposed that a fine-grained sedimentary unit which bounds the marble discussed above along its eastern margin (CS_3 of Figure 2) represents Paleozoic eugeoclinal strata that are in turn overlain in apparent angular unconformity by "essentially undeformed" Triassic volcanic sandstone and conglomerate to the east (Br of Figure 2). We consider this fine-grained sedimentary unit (the White Chief unit of Busby-Spera, 1984a,b) to be a Triassic unit that conformably underlies the volcanic sandstone and conglomerate for the following reasons: 1) The protolith of the fine-grained sedimentary unit is identical to that of five other map units in the pendant, some of which contain Triassic and Jurassic marine fossils, referred to as calcsilicate (CS) map units 1 through 6 by Busby-Spera and Saleeby (1987). These consist of thin-bedded calcareous siltstones and fine-grained sandstones and tuffs, as well as marbles and pelites (Busby-Spera, 1984a). 2) The siliceous layers in the fine-grained sedimentary unit are not the cherts and fine-grained quartzites typical of eugeoclinal rocks, as suggested by Schweickert and Lahren (1991). They are dominantly distal silicic tuffs that formed by settling of ash through the water column into a deep marine environment (see "calcareous siltstone-limestone unit" of Kokelaar and Busby, 1992). 3) Schweickert and Lahren's inferred angular unconformity at the top of the fine-grained sedimentary unit was defined on the basis of a decrease in the degree of deformation across the contact. As noted above, deformational style in the Mineral King pendant is strongly dependent on lithology. 4) The "essentially undeformed volcanic sandstone and volcanic conglomerate" of Schweickert and Lahren (1991) is actually a breccia-sandstone unit (Br or "Sunridge unit" of Busby-Spera, 1984a,b). It is interpreted to represent an apron of debris shed from the scarp of a normal fault that acted as a conduit for eruptions precursoral to the major caldera-forming eruption of the Vandever Mountain tuff (R_1). The breccia-sandstone unit does not occur in lenses as Schweickert and Lahren (1991) report, but instead forms a continuous map unit in the floor of the Vandever Mountain caldera (Busby-Spera, 1984b; Busby-Spera and Saleeby, 1987; Kokelaar and Busby, 1992). We interpret the lower contact of the breccia-sandstone unit as a gradational, concordant contact (not an angular unconformity) because similar siltstone horizons occur several tens of meters above and below the contact (Kokelaar and Busby, 1992).

In summary, there is no compelling evidence for a structure of the proposed magnitude of the Mojave-Snow Lake fault, nor for miogeoclinal, or eugeoclinal rocks in the Mineral King pendant. Speculations indicating the existence of any of these were based on an incomplete understanding of the overall stratigraphy and structure of the pendant.

Lake Isabella and Kern Canyon Pendants

Two distinct sequences of lower Mesozoic and possibly older metasedimentary rocks occur as the Lake Isabella and Kern Canyon pendants (Saleeby and Busby-Spera, 1986). They are currently separated by the proto-Kern Canyon fault zone and the related belt of mylonitic granitic rocks of Cretaceous age. A generalized map and diagrammatic structural-stratigraphic sections for each of the pendants are given in Figure 3.

The Isabella section is constructed from high-grade metamorphic rocks exposed mainly southeast of Lake Isabella. The section is apparently intact with no apparent major structural breaks, although high-temperature synbatholithic ductile strain is extreme with near vertical stretch factors of ~10. The apparent base of the section consists of up to 2 km of pelitic and psammitic schist with thin marble and calcsilicate lenses and mafic metavolcanic lenses that range up to 500 m in thickness and rare intervals of metachert; all thicknesses are structural. Above these rocks lies a laterally continuous grey marble layer which ranges between 15 and 100 m in thickness. Above the marble lies a quartz-rich unit with local thick bedded pure quartz arenite, quartzite pebble conglomerate, laminated biotite-rich quartzite and psammite, calcareous quartz arenite, siliceous calcsilicate, and scattered marble lenses. Calcareous quartz-arenite and calcsilicate rock yield Late Triassic(?)-Early Jurassic Weyla bivalves at several localities (Saleeby and others, 1978; Saleeby and Busby-Spera, 1986, and unpublished data). The quartz-rich unit ranges between 300 and 500 m in thickness. It grades abruptly into at least 1200 m of turbiditic pelite which constitutes the apparent top of the section. The pelite could have been substantially thicker, but to the south, apparently up section, it becomes highly migmatitic and is commingled with Cretaceous batholithic rocks.

The Kings sequence rocks southeast of Lake Isabella appear to record the shoaling of a basinal environment with mafic volcanic activity into a Late Triassic carbonate bank or reef environment, followed by Late Triassic or Early Jurassic shallow water quartz-rich sedimentation with abundant carbonate. This shelfal(?) environment subsequently became basinal in Early to Middle(?) Jurassic time, and accumulated a thick section of thin-bedded turbidites. The calcareous quartz arenites and siliceous calcsilicate rocks that contain the Weyla strongly resemble strata in the Mineral King pendant that depositionally overlies a Lower Jurassic ignimbrite dated by U/Pb zircon. The immediately underlying continuous marble in the Isabella pendant is believed to be Carnian-Norian in age as is one of the main marble horizons in the Mineral King pendant. Possible correlative strata to the lower metabasalt-marble-pelite sequence occurs in the medial levels of the Kern Canyon pendant.

High-grade metamorphic and ductile deformation features that affected the Isabella pendant at ~100 Ma during batholithic activity are overprinted and truncated by high shear strain structures and medium to high grade metamorphic textures of the proto-Kern Canyon fault zone (Saleeby and Busby-

Spera, 1986; Saleeby, 1992). A tail-like structure of high-grade Isabella pendant rocks is strung out for ~10 km northward along the dextral shear zone (Fig. 3). The tail is intruded by and sheared against 85 Ma mylonitic granite of the shear zone. It is also juxtaposed to the west by high shear strain Kern Canyon pendant rocks.

The Kern Canyon pendant extends for ~35 km along the Kern River mainly north of Kernville. Higher grade equivalent rocks are present in small screens to the south and west. Along the central segment of the pendant, well-preserved primary features remain due to an anomalously low-pressure (high level) domain of the batholith having been preserved along the proto-Kern Canyon fault zone (Ague and Brimhall, 1988b; Saleeby, 1992a). The pendant in part constitutes a portion of the roof of a mid-Cretaceous shallow level intrusive complex; unlike most screens of the Kings sequence, pre-batholithic structures are well-preserved in the roof-level metasedimentary rocks. The early structures consist mainly of NW to E-W striking, south dipping foliation and bedding surfaces, and NNE-directed thrust faults and associated folds. These structures are strongly transposed by the ~NS ductile shear fabric of the proto-Kern Canyon fault (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1989; Saleeby, 1992).

Figure 3 contains a diagrammatic structural-stratigraphic section along the central segment of the pendant where the high-level roof rocks are present. Total thickness is highly uncertain because of imbricate thrust structure. The apparent base of the section consists of polydeformed thin- to thick-bedded quartzite and micaceous quartzite with possible infolds or fault slivers of less deformed quartz ± silicic volcaniclastic arenite. Above the lower-level quartzites lies a sequence of marble, pelite-psammite, and local mafic volcanic and/or hypabyssal layers that is up to 500 m thick. The upper part of the section consists of mixed silicic volcaniclastic and quartz detritus channelized turbidites that are locally very similar to the Bullfrog fan sequence in the Mineral King pendant. Finer grained, calcareous quartz sandstone and siliceous calcsilicates and thin-bedded quartz arenites also occur in the section, and these appear turbiditic as well. The calcareous quartz sandstones and calcsilicates compositionally resemble the Weyla-bearing strata of the Isabella pendant. They also contain similar mid-Proterozoic detrital zircon populations (Saleeby, unpublished data). For this reason and because of the similarities with early Mesozoic turbiditic strata to the north in the Mineral King and Boyden Cave pendants, we interpret the Kern Canyon turbidites as early Mesozoic in age.

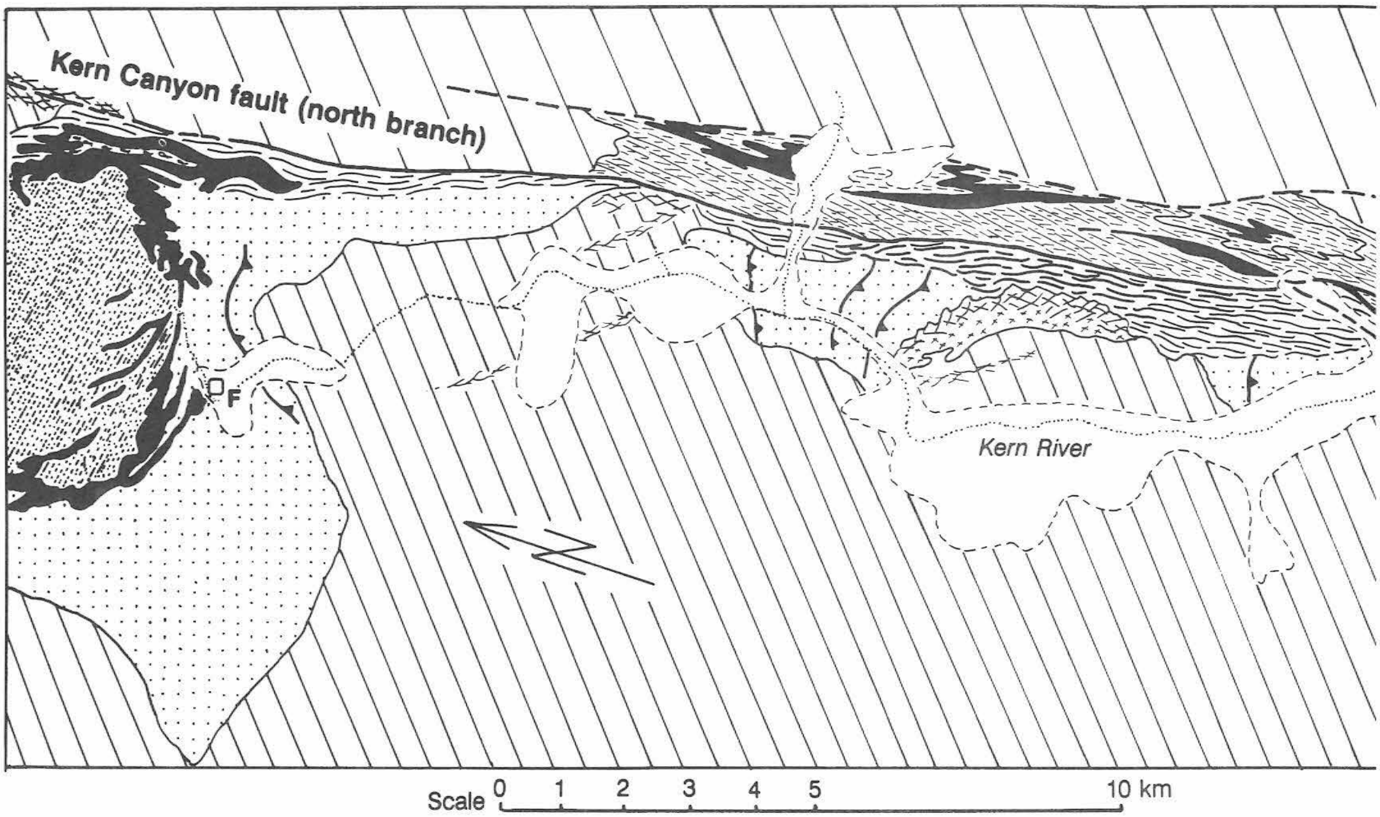
The Kern Canyon pendant appears to record deposition of quartz-rich sand and grit, shallow water carbonates, and mafic volcanics over an older, previously deformed metaquartzite basement. We tentatively assume that the main pulse of carbonate deposition is Carnian-Norian in age based on the carbonate ages of the Mineral King pendant to the north and Isabella to the south. The Late Triassic shallow water environment subsided in Late Triassic to Early Jurassic time, resulting in the deposition of partly channelized turbidites derived from a mixed silicic volcanic, reworked continental basement and carbonate rich shelf environment. The Kern Canyon pendant thus contains elements of the early Mesozoic stratigraphic history recorded in both the Mineral King and Isabella pendants.

Based on lithologic character and polyphase deformation, Schweickert and Lahren (1991) correlated the Kern Canyon pendant with the Shoo Fly complex of the western Sierra metamorphic belt. Much of the polyphase deformation they noted is related to Cretaceous ductile shearing along the proto-Kern Canyon fault zone, and thus the structural analogy is incorrect. Polydeformed metaquartzites at the apparent base of the Kern Canyon section could, however, represent a Shoo Fly-affinity basement that the early Mesozoic section was built on, and partly derived from. Similar structurally complex quartzites constitute the southeastern carbonate-poor portion of the upper Tule River pendants (Fig. 1b) which are discussed below.

<u>Boyden Cave Pendant</u>

The stratigraphy of the Boyden Cave pendant has been discussed by Moore and Marks (1972), Jones and Moore (1973), Saleeby and others (1978, 1990), Girty (1985), and Schweickert and Lahren (1991). The dominant structure is NNW-striking steeply-dipping high-temperature foliation with a down-dip lineation, shared by metasedimentary rocks and by mid-Cretaceous metavolcanic and shallow-level intrusive rocks previously thought to be early Mesozoic in age. The dominant steep fabric is grossly concordant to enclosing mid-Cretaceous plutons and reflects synbatholithic ductile deformation. Earlier pre-batholithic structures have been flattened and/or transposed into this fabric.

A generalized map and structural-stratigraphic section for the Boyden Cave metasedimentary units are given in Figure 4. The apparent base of the section consists of highly intruded and contorted thinly layered calcsilicate gneiss, marble and impure quartzite-psammite and pelite (mixed schist unit). This grades into ~1 km thick, thin to thick-bedded feldspathic quartzite with thin micaceous interbeds. Cross-bedding is locally well preserved, and in conjunction with numerous micaceous laminae, is suggested to pervade the entire unit (Girty, 1985). Tight to isoclinal folds are exceedingly rare, suggesting the unit is either homoclinal or that the steep mid-Cretaceous fabric has strongly transposed earlier structure; considering its map pattern, the later is more likely, and thus the original thickness of the quartzite unit is unconstrained. Above the quartzite is a zone of discontinuous marble lenses that are up to



MAP EXPLANATION

unconsolidated sediments

PROTO-KERN CANYON FAULT ZONE

brittle fault

concealed bounds of shear zone

pervasive cataclasis

Quartz-rich phyllonite & mylonite with vestigual lenses of quartzite, marble and mid-Cretaceous metavolcanic rocks

Synmagmatic mylonitization of ~85 Ma phase of granodiorite of Castle Rock

ROCKS WEST OF THE PROTO-KERN CANYON FAULT ZONE

Mid-Cretaceous (~90 to 100 Ma) shallow-level Granite of the Kern River

Kern Canyon Pendant

Andalusite-bearing metamorphic rocks with protolith features and stratigraphic relationships locally preserved

Hypabyssal intrusive complex, local vent facies included (~100 Ma)

Upper turbiditic metasedimentary unit (lw. Mz)

Marble, with amphibolite lenses & pelite-psammite (lw. Mz)

Lower quartzose metasedimentary unit (Pz?)

pre-Cretaceous thrust fault

ROCKS EAST OF THE PROTO-KERN CANYON FAULT ZONE

Late (~85 to 90 Ma) Cretaceous granodiorite Castle Rock

Granodiorite of Rabbit Island (~100 Ma)

Cyrus Flat mafic intrusion (~100 Ma)

Isabella Pendant

Mid-Cretaceous-sillimanite grade metamorphism and local migmatization of lower Mesozoic strata

Pelitic and psammitic schist, gneiss and migmatite

Quartzite, quartz schist, calcsilicate rock and local marble

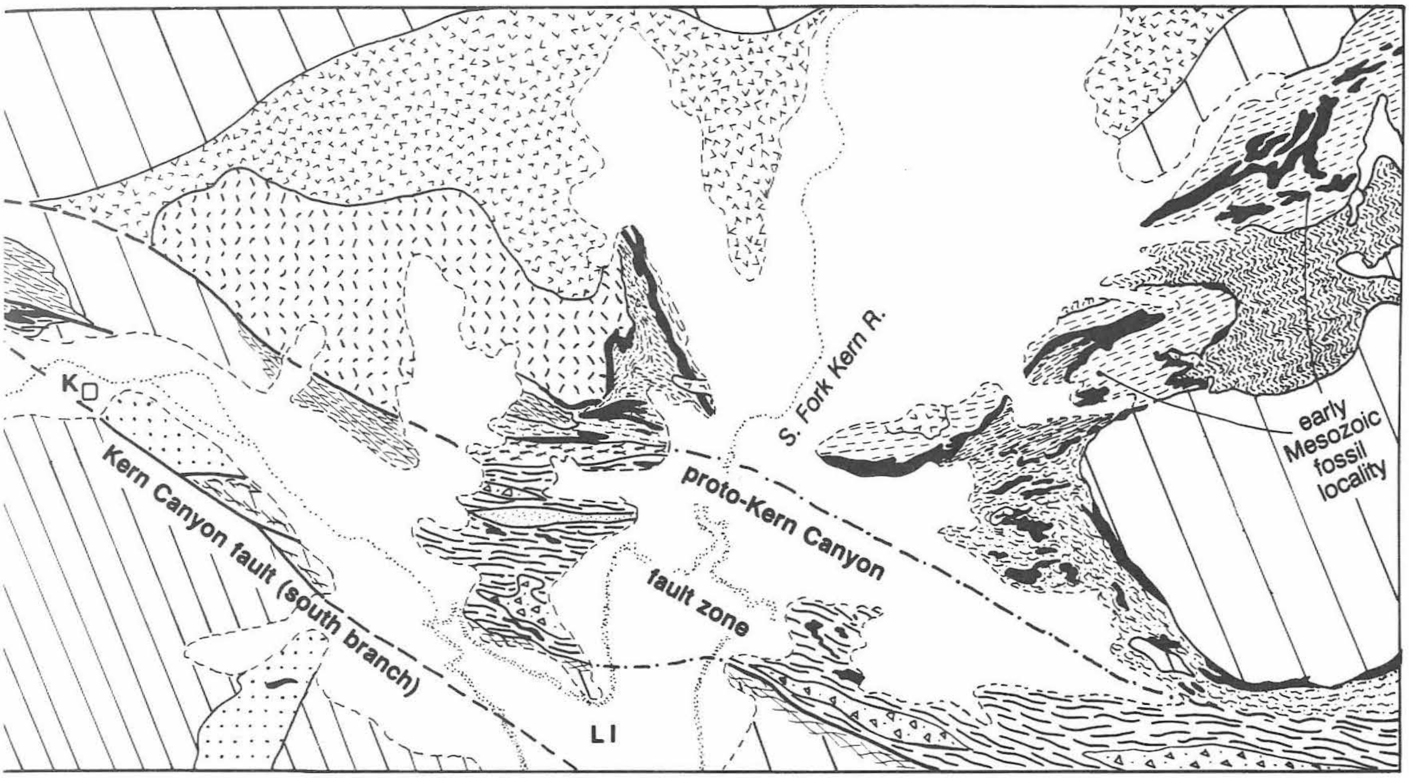
Marble with calcsilicate layers

Amphibolite with local calcsilicate rock and marble layers

Pelitic schist

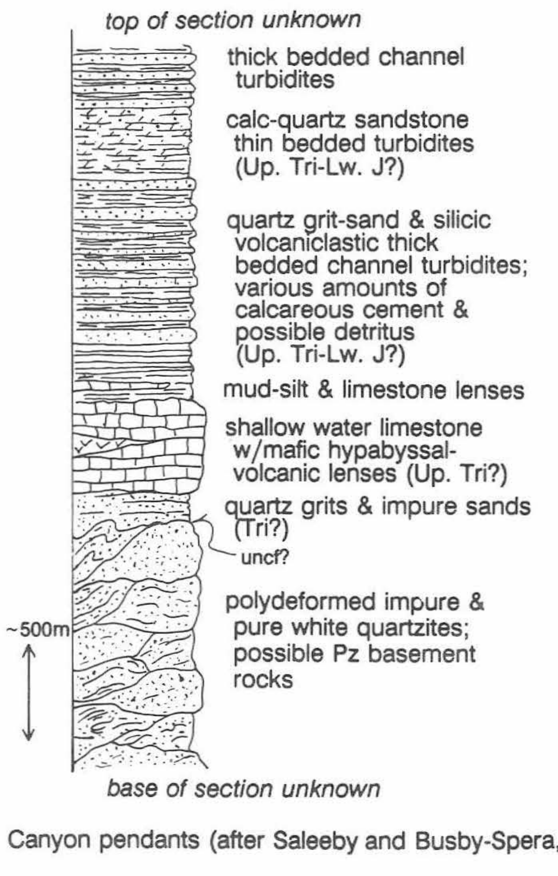
Mixed pelitic, psammitic and quartz-rich schist

Figure 3. Geologic map and structural-stratigraphic columns of part of the Isabella and Kern

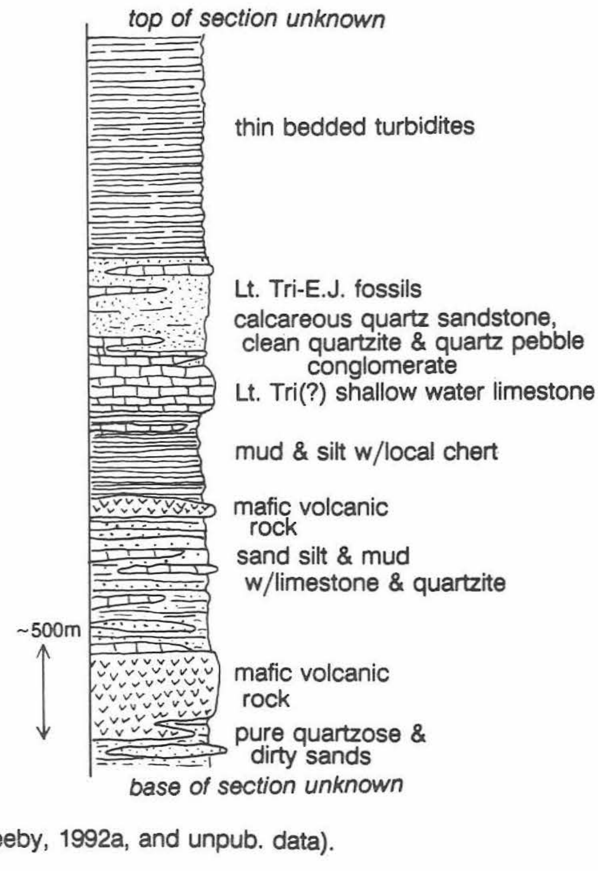


Map Abbreviations: **F** Fairview **K** Kernville **LI** Lake Isabella

RECONSTRUCTED STRATIGRAPHY OF KERN CANYON PENDANT
(Thickness uncertain)



RECONSTRUCTED STRATIGRAPHY OF ISABELLA PENDANT
(Thickness uncertain)



Canyon pendants (after Saleeby and Busby-Spera, 1986; Saleeby, 1992a, and unpub. data).

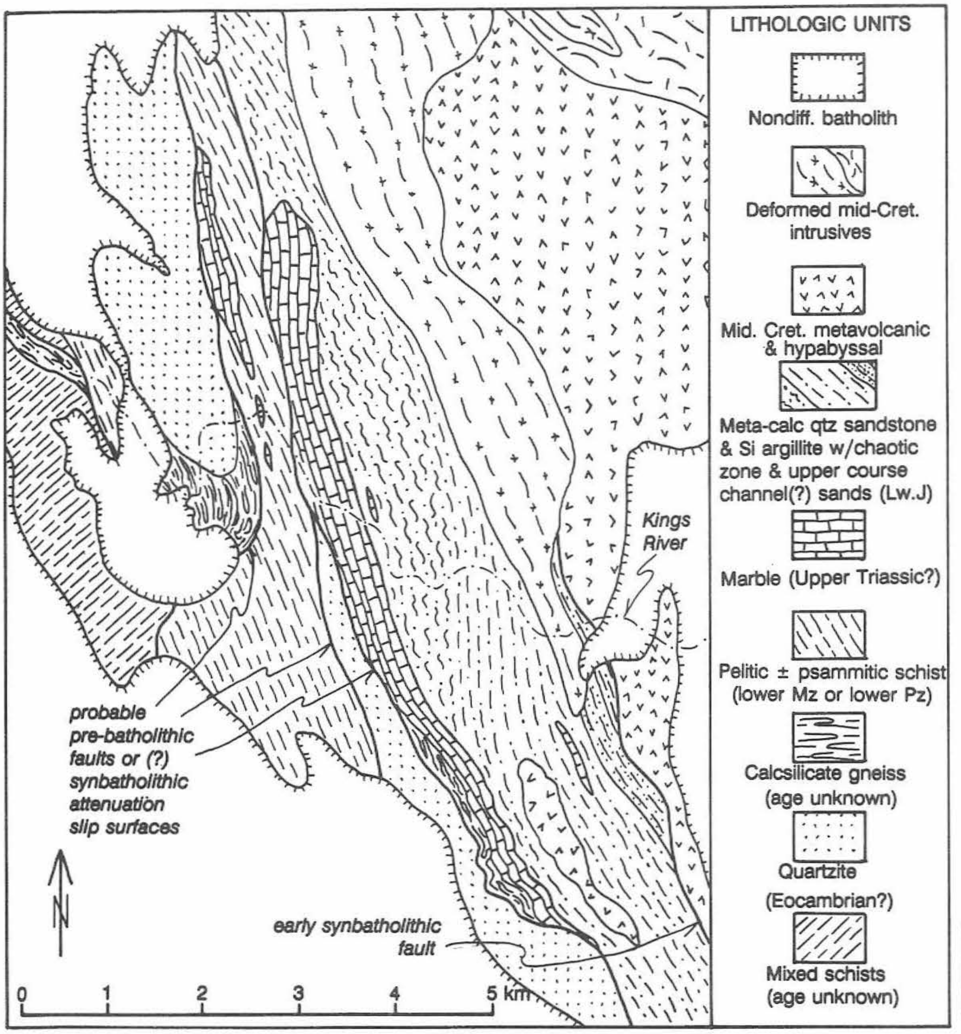


Figure 4. Geologic map and structural-stratigraphic column of Boyden Cave pendant (after Moore and Marks, 1972; Saleeby and others, 1978, 1990; Girty, 1985; Saleeby unpub. data).

50 m thick. This appears to represent a pre-batholithic fault or shear zone based on numerous discordances in lithologic layering. To the south the marbles pinch out in pelitic-psammitic schist, and the schist and probable fault wrap around highly contorted calcsilicate gneiss. The enveloping unit is at least a 500 m thick consisting primarily of interlayered pelite-psammite with rare marble lenses. Above the pelite-psammite lies a ~500 m thick massive to locally laminated grey marble. Discordances in gross lithologic layering suggest that another structural break lies between the pelite-psammite and the marble. Lenses of highly strained quartzite and calcsilicate gneiss occur southward along this probable fault. The only confirmed early Mesozoic strata lie above (east) of the thick marble unit.

Above the marble unit lies a 1.5 km thick section of chaotic olistostromal rock that grades abruptly upwards into thin bedded turbidites. The chaotic unit ranges from 200 m to ~1 km in thickness and partly encases the northern end of the underlying marble. It contains sub-angular to rounded blocks and contorted slump domains of calcareous quartzite and siliceous calcsilicate rock, and irregular blocks of laminated siliceous argillite-calcareous quartzite all scattered in a siliceous argillite matrix. Most of the blocks are indigenous to the siliceous argillite matrix, but rare exotic blocks and clasts of marble and intermediate to felsic volcanic rock are also present. An Early Jurassic ammonite was recovered from a slightly out of place slab of matrix material (Saleeby and others, 1978). The chaotic rocks grade upward into a monotonous sequence of finely laminated to thin-bedded turbidites that ranges up to ~1 km thick. The turbiditic sandstone consists of calcareous quartz arenite as well as more highly recrystallized siliceous calcsilicate; the turbidite sequence is compositionally similar or identical to disrupted, generally thin-bedded, contorted domains of the chaotic unit. Near the apparent top of the turbidites layers of volcaniclastic sandstone occur, and to the south thick-bedded quartz-rich channelized (?) sandstones occur. Jones and Moore (1973) recovered Early Jurassic ammonites from talus derived from the fine-grained laminated turbidite interval above the chaotic rocks. Abundant well-preserved facing indicators consistently show up to the east in the turbidites, indicating that the chaotic rocks indeed grade upward into the turbidite sequence. These facing data form the basis for interpreting the more westerly units as lying stratigraphically lower in the section.

There has been considerable debate over whether or not the Early Jurassic fossils are at all pertinent to the age of the units beneath the chaotic unit. Based primarily on regional tectonic arguments, Schweickert and Lahren (1991) suggest that the lower part of the section represents displaced Eocambrian-Cambrian rocks of the miogeocline akin to those of the Snow Lake pendant to the north (Figure 1a). Lithologic constraints are poor, except for the thick quartzite unit, and there are no compelling stratigraphic constraints, necessitating omission of complete miogeoclinal units by faulting, in order to explain the observed lithologic sequence. Nevertheless, we feel that Schweickert and Lahren's (1991) correlation of the lower quartzite unit to the upper Proterozoic Stirling Quartzite of the miogeocline is reasonable, although their inclusion of the mixed schists and calcsilicate gneiss units in their Stirling unit is questionable. Their correlations higher in the section are much more speculative. The pelite-psammite and marble units are lithologically non-distinct when compared to early Mesozoic rocks of the Kings sequence, and we could not substantiate the stated correlations to the Wood Canyon and Bonanza King Formations, respectively, in our observations of the type section in the Nopah Range (Stewart, 1970).

Our preferred interpretation for the Boyden Cave section is the early Mesozoic deposition of much of the section above a previously deformed miogeoclinal fragment (after Schweickert and Lahren, 1991) represented primarily by the quartzite unit. Our preferred origin for the thick marble unit is Carnian-Norian carbonate bank and/or reef deposition followed by Early Jurassic subsidence and the overlying basinal sedimentation. The lensing out of the marble unit with the partial envelopment by the chaotic unit in conjunction with the structural discontinuities along its base suggest that the marble itself could be a large slide mass that moved downslope into the Early Jurassic basin to be concurrently or subsequently covered by olistostromes. The underlying pelite-psammite unit and marble lenses could be all, or in part, Late Triassic-Early Jurassic in age, with a basal fault or slipped unconformity against the mainly quartzite basement. Alternatively, all units west of the thick marble could be disrupted miogeoclinal basement below a slipped unconformity at the base of the Carnian-Norian carbonates. The tectonic breaks and/or displacements along unconformities could have occurred during Late Triassic-Early Jurassic extension in the Kings sequence basin, and/or Middle to Late Jurassic contraction of the basin, both discussed below. The structural breaks may also in part represent slip surfaces along lithologic contrasts which in part accommodated synbatholithic attenuation of the pendant.

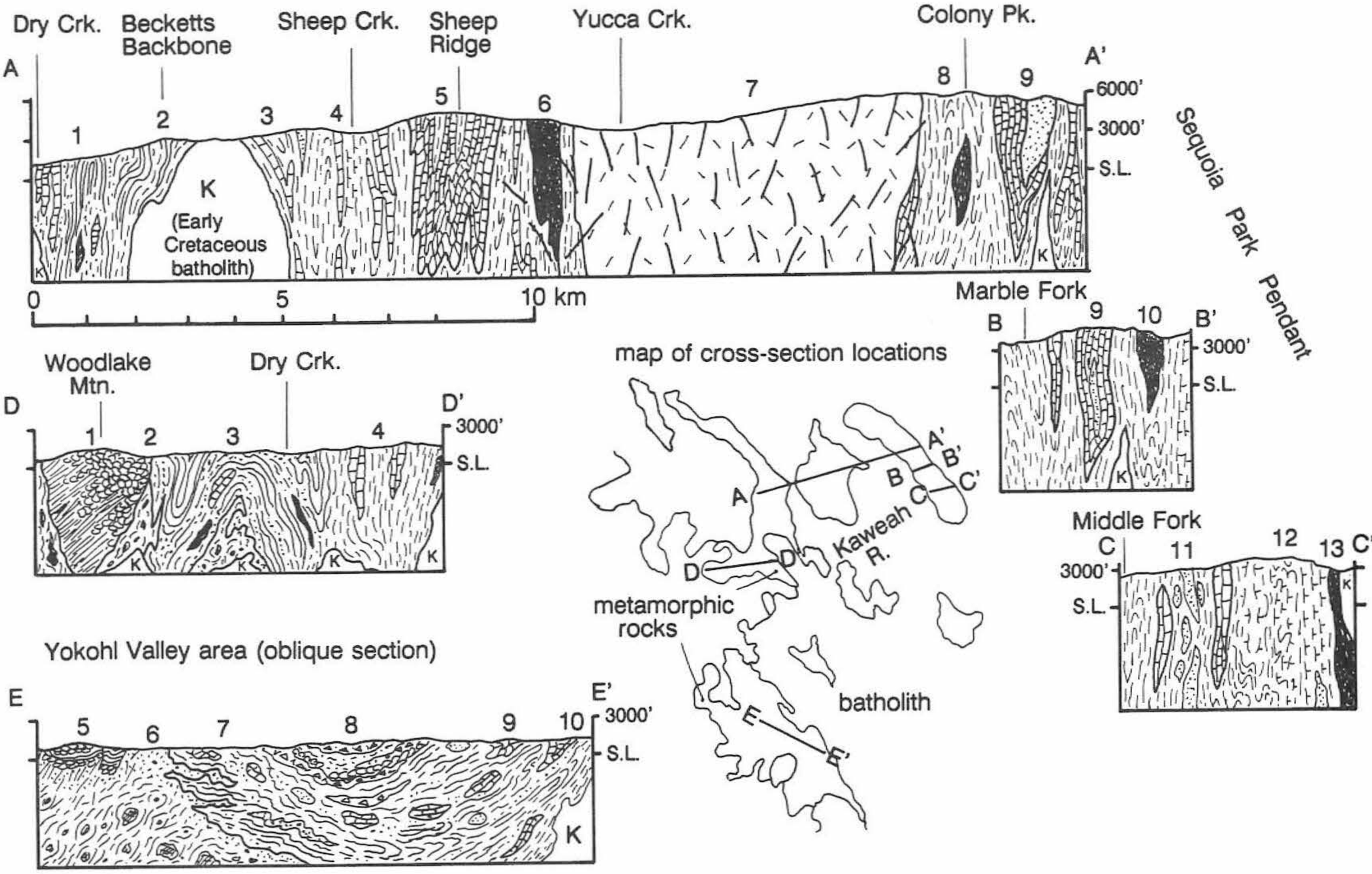
The Lower Jurassic chaotic and turbiditic sequence records basinal sedimentation above the Carnian-Norian(?) carbonate sequence with the influx of mixed quartzose and carbonate detritus, subordinate volcanic material and reworked carbonate clasts. The compositions of the thicker turbidite sand beds are very similar to the Weyla-bearing shallow water calcareous quartz sands of the Isabella pendant, and are compositionally, structurally and texturally similar to the calcareous quartz sand turbidite layers in the Kern Canyon pendant (Fig. 3).

Nokleberg (1983) indicated a fundamental tectonic break between the chaotic unit and the turbidites (Kings River fault). If there is a tectonic break present, it is not fundamental. There could be a syndepositional low-angle fault that perhaps promoted part of the widespread soft sediment deformation that is so well preserved in the chaotic unit. Such a hypothetical fault occurred within an otherwise consanguineous stratigraphic unit. Part of Nokleberg's (1983) reasoning was based on the interpretation of the disrupted fabric of the chaotic unit being tectonic in origin. This reasoning is incorrect, for a rather well-preserved ammonite was recovered from the matrix material indicating that it was not produced by pervasive shearing. Furthermore, Nokleberg (1983) did not appreciate the importance of the superposed mid-Cretaceous synbatholithic deformation fabric. As discussed below, and in Kistler (this volume) there is reason to suspect a major early synbatholithic break (AIB) between the metasedimentary and metavolcanic units of the pendant (Fig. 4).

Metasedimentary rocks that are similar to those of the Boyden Cave pendant occur to the northwest (Fig. 1a) in the Patterson Mountain pendant (Saleeby, unpub. data) and in the Dinkey Creek pendant (Kistler and Bateman, 1966). The Patterson Mountain pendant consists primarily of highly recrystallized quartzite that is very similar to the lower quartzite unit of Boyden Cave. The Dinkey Creek pendant likewise contains the distinctive thick quartzite, but in addition to mixed schists, marble and pelite. We interpret Patterson Mountain as primarily a miogeoclinal fragment and Dinkey Creek as a possible composite of both miogeoclinal and overlapping lower Mesozoic Kings sequence strata like Boyden Cave (modified from Schweickert and Lahren, 1991).

Metasedimentary Rocks Associated with the Kings-Kaweah Ophiolite Belt

Metasedimentary and subordinate metavolcanic rocks are faulted against the Kings-Kaweah ophiolite belt between the lower Kings and Kaweah Rivers, and are folded and faulted into the ophiolite belt in areas extending south of the lower Tule River (Saleeby, 1977, 1978, 1979, 1982, 1990b). In general metasedimentary rocks of the lower



EXPLANATION

Sections A, B and C

1. Folded bedded chert and argillite with interbedded siltstone and diamictite, local marble layers and rare amphibolite lenses.
2. Psammitic > pelitic schist with remnant of sand-silt and chert beds.
3. Psammitic > pelitic schist with local metachert layers.
4. Psammitic schist with layers of grey marble, buff quartzite and calcsilicates derived from calcareous quartz sandstone, local lenses of possible metachert.
5. Highly contorted grey marble with interlayered psammitic schist and calcsilicates.
6. Amphibolite derived from mafic volcanic rock; margins are interlayered with grey marble, psammitic schist and quartzite.
7. Middle Jurassic granodiorite of Yucca Mountain and ~150 Ma mafic to felsic dike swarm.
8. Psammitic > pelitic schist with thin calcareous metaquartzite, calcsilicate and amphibolite layers.
9. Grey marble and buff quartzite within psammitic-pelitic schist.
10. Amphibolite derived from mafic volcanic rock within thinly interlayered psammitic-pelitic schist and quartzite.
11. Blocks and lenses of buff quartzite within schistose quartzite fragment diamictite, and psammitic-pelitic schist with marble layers.
12. Calcsilicate rock derived from thinly bedded calcareous quartz sandstone and interlayered psammitic-pelitic schist.
13. Amphibolite derived from mafic volcanic rock.

Sections D and E

1. Slab of ophiolitic metabasalt and metadiabase bounded by serpentinite melange.
2. Tectonic contact.
3. Folded bedded chert and argillite with interbedded turbiditic siltstone and diamictite and blocks of marble and amphibolite.
4. Psammitic > pelitic schist with local remnants of sand-silt and chert beds, local marble and amphibolite layers.
5. Lower Mesozoic basaltic pillow lava, dike rock and chert with argillaceous and tuffaceous admixtures.
6. Sedimentary serpentinite, ophicalcite, ophiolitic olistostromes and underlying serpentinite melange.
7. Lower Mesozoic siliceous and tuffaceous argillite, chert-argillite-arenite olistostromes, blocks of marble and quartz arenite.
8. Lower Mesozoic boninitic pillow lava and volcaniclastic rock, tuffaceous and siliceous argillite, lithic and quartzose turbidites.
9. Permian Tethyan-affinity limestone blocks in chert-argillite-arenite olistostromes also with blocks of bedded chert and local quartz arenite.
10. Marble, psammitic-pelitic schist and local metachert layers.

Figure 5. Series of stepped cross-sections showing major lithologic-stratigraphic features of Kings sequence pendants along Kaweah River area between Sequoia Park and western Foothills (references given in text).

Kings River and much of the Kaweah and Tule River drainages are remarkably similar to one another. The similarities include overall lithologic association, structure and metamorphism, and a general east-to-west increase in the amount of metachert present. We interpret this regional belt of pendants as the remnants of the imbricated, and subsequently highly intruded and attenuated, Kings sequence forearc basin. Pelite, psammite and siliceous and carbonaceous argillite are the dominant lithotypes, which encase various admixtures of metavolcanic, carbonate and quartz-rich rocks. Based on batholithic petrochemical patterns discussed above, this belt of pendants lies west of the CLB

(Fig. 1a), but encompasses the $Sr_i = 0.706$ isopleth. Our interpretation of 0.706 isopleth in this region is that it reflects an outer ridge in the forearc basin where ophiolitic basement was uplifted, and thereby formed a tectonic dam that restricted further westward dispersal of continent ± arc-derived detritus. Mantle-derived batholithic magmas interacted extensively with these detrital rocks east of the 0.706 line, and considerably less to the west.

The lithologic character, across-strike variation and structural complexity of this belt of pendants is summarized in a series of stepping cross-sections for pendants of the lower Kaweah River drainage (Fig. 5). The steps in the cross-sections are made within laterally continuous and/or lithologically identical lithosomes. The cross-sections start in the largest of the Sequoia Park pendants on the east and progress to the Yokohl Valley area of the Foothills metamorphic belt to the west (after Durrell, 1940; Ross, 1958; Saleeby and others, 1978; Saleeby, 1979; Sisson and Moore, in press; Saleeby and J.G. Moore, unpub. data). Stratigraphic relations that support the outer ophiolitic ridge interpretation are best preserved in the Yokohl Valley area.

Ophiolitic basement rocks of the Yokohl Valley area consist of Carboniferous serpentinite-matrix melange and variably bedded to disrupted metachert (Saleeby and others, 1978; Saleeby, 1979, 1982; Saleeby and Sharp, 1980). Lower Mesozoic rocks consist of a complex mixture of interbedded chert and tholeiitic pillow lava, basement-derived debris flow deposits, chert-argillite-arenite olistostromes, and mixed quartzose to silicic volcaniclastic turbidites. These grade upward into lithic and quartzose turbidites, siliceous and tuffaceous argillite, and lenses of boninitic pillow lava and pyroclastic rock. Age constraints on the section are as follows: 1) Chert-argillite-arenite olistostromes contain Permian (Tethyan affinity) olistoliths making the olistostromes Permian or younger; 2) Late Triassic to possible earliest Jurassic dikes (discordant zircon ages) occur in association with tholeiitic pillow lava chert and sedimentary serpentinite; some are peperitic, and thus this approximates the age of at least part of the lower section; 3) Poorly preserved Jurassic ammonite remains were recovered at an inferred high stratigraphic level from fine-grained turbidites; and 4) A 170 Ma dike cross-cuts a high-level boninite lens which, in conjunction with the above relations, constrains much of the section as Late Triassic to early Middle Jurassic in age.

The ophiolitic basement high is recorded in the Yokohl Valley section by the early Mesozoic dikes, pillow lavas and chert that were constructed directly on ultramafic rock, and by the occurrence of discrete olistostromes as well as detritus of these rocks, including ultramafics, within basinal strata immediately to the east. These same basinal strata contain admixtures of quartz detritus and silicic volcaniclastic material presumably derived from mixed continental and arc sources further to the east.

Various components of the Yokohl Valley section are present along the entire eastern margin of the ophiolite belt. Southward from the Yokohl Valley area, chert-argillite, turbidites and minor boninitic volcanic rocks bound the eastern margin of, and occur as infolds within, the ophiolite belt, and in turn feather southeastward into high-grade screens south of the lower Tule River. Northward from the Yokohl Valley area, high-grade chert-argillite, thin bedded turbidites and olistostromes, as well as mafic metavolcanic, quartzite and marble lenses, continue as screens between the lower Kaweah and lower Kings Rivers areas. The chert-rich strata are well-preserved in the Dry Creek to Becketts Backbone area (Fig. 5), but are of higher metamorphic grade than in much of the Yokohl Valley area. Interlayered pelitic and psammitic schists locally preserve turbidite and diamictite features in this area as in the Yokohl Valley area.

The lithologic sequence summarized for the lower Kaweah River region in Figure 5 is representative of the sequence preserved in the lower Kings River pendants as well (Saleeby and others, 1978, unpub. data). In general the proportion of recognizable metachert decreases eastward as the amount of feldspathic quartz-arenite, marble, and calcsilicate rock and siliceous calcsilicate rock (calcareous quartz arenite) increase. Mafic metavolcanic lenses are scattered throughout the sequence, and psammitic and pelitic schist persist as the dominant lithotypes. The psammitic schists are commonly banded reflecting concentrations of siliciclastic, cherty, and/or volcaniclastic material. Remnants of turbidite and diamictite features are locally well-preserved in the schists of both regions, but a transposition foliation/lineation is the dominant feature. Various degrees of transposition and folding of copious syn-metamorphic quartz veins also complicate the structure of the schists. We emphasize that quartz arenites occur in the same strata as cherts in sections A, D and E of Figure 5, and in widely dispersed localities of the lower Kings River pendants. The quartz arenites occur as thin beds, large blocks and lenses, and as pebbles in diamictite and quartzite conglomerate.

The overall lithologic assemblage between the Sheep Creek area of section A and progressing east through sections B and C (Fig. 5) is remarkably consistent in character. This assemblage is virtually identical to the presumed lower and the medial Weyla-bearing levels of the Isabella pendant section (Figure 4). Our preferred age for the Sheep Creek to Sequoia Park sequence is thus Late(?) Triassic-Early Jurassic. We feel particularly confident of this age for strata that contain the distinctive calcareous quartz arenites, similar to those that contain Weyla in the

Isabella pendant, those that are interbedded with Lower Jurassic ash flow tuff in the Mineral King pendant, and those that contain Early Jurassic fossils in the Boyden Cave pendant. We also recognize the possibility that quartz arenite and marble blocks could have been derived as olistoliths from miogeoclinal basement to the east, and/or some isolated marble blocks could be Permian Tethyan-affinity olistoliths similar to those of the Yokohl Valley area. Furthermore, Early Triassic limestone beds occur in both argillaceous-arenaceous and chert-argillite units of the Calaveras complex to the north (Bateman and others, 1985). As discussed below, the western chert-bearing facies of the Kings sequence probably correlates with the Calaveras complex, and thus some of the marble layers could be Early Triassic in age.

Lower Mesozoic rocks of the southern Foothills preserved best in the Yokohl Valley area resemble the southern Calaveras complex (Schweickert and others, 1977), particularly in its western gradation of chert-argillite into Sullivan Creek (or Don Pedro) terrane mixed lithic, quartzose and volcaniclastic turbidites, and the more westerly interfingering Lower to Middle Jurassic mafic metavolcanic rocks (Sharp, 1988). Similar complex mixtures of lower Mesozoic volcanic and sedimentary rocks with Paleozoic ophiolitic basement occur in the Central belt of the western Foothills further north (Clark, 1965; Duffield and Sharp, 1975; Behrman and Parkison, 1978; Saleeby, 1982, 1990b). Schweickert and Lahren (1991) have extended the Calaveras complex and the Sullivan Creek terrane into the lower Kings, Kaweah and Tule Rivers region, and by inference the Sonora fault, a presumed terrane boundary between the two. The Sonora fault is highly questionable as a fundamental break even in its type area in the western Foothills belt (see discussion below). The proposed trace of the Sonora fault in the Yokohl Valley area (loc. 7 on Fig. 5, section E) projects obliquely across the pervasive structure of the area, and has the same rocks but in different proportions on both sides of it. Schweickert and Lahren (1991) also extended the Shoo Fly-Calaveras thrust through the lower Kings, Kaweah and Tule Rivers region. The position of their proposed thrust is along the eastern margin of abundant metachert in pendants of the lower Kings and Kaweah Rivers region (cf. between locs. 2 and 3, Fig. 5, section A). Metachert is widespread, but subordinate to the east of this position, however, particularly in the lower Kings River area. Furthermore, rocks shown as Shoo Fly complex in the lower Kaweah River area (locs. 3 through 6, section A) are virtually the identical sequence of rocks also shown by Schweickert and Lahren (1991) as Snow Lake block in the Sequoia Park pendant (locs. 8 through 13, sections A, B and C).

TERRANE ANALYSIS OF THE SOUTHERN SIERRA NEVADA

In the previous sections we have reviewed the stratigraphic framework of the metamorphic pendants of the southern Sierra Nevada as well as the regional structure of the Cretaceous batholith and its gross petrochemical patterns in relation to framework compositional patterns. In this section we will consider the problem of terrane analysis in the region taking into consideration pre-Mesozoic basement structure, early Mesozoic sedimentation and tectonics, and Cretaceous synbatholithic dextral faulting.

Lithospheric Framework

In analyzing the pre-batholithic tectonic and stratigraphic framework of the southern Sierra Nevada, we will integrate the constraints on pre-batholithic basement rocks posed by the batholithic petrochemical patterns with the sparse stratigraphic relations we have discussed above, and also a variety of tectonic-paleogeographic models for the region (Saleeby and others, 1978; Saleeby, 1977, 1992b; Schweickert and Lahren, 1991; Saleeby and Busby-Spera, 1992). The boldest attempt to make stratigraphic correlations from extraneous intact sections into the southern Sierra Nevada metamorphic framework is that of Schweickert and Lahren (1991). Their analysis was predicated on the existence of a large intact block of miogeoclinal strata (Snow Lake block) having been offset from the Mojave region into the axial Sierra Nevada by Early Cretaceous dextral faulting (Snow Lake fault). Lithologic, stratigraphic and trace-fossil arguments were made for the existence of Eocambrian-Cambrian strata in the Snow Lake pendant (Fig. 1a), and more speculative arguments were raised for the existence of such strata in the Dinkey Creek, Boyden Cave, Sequoia Park and Mineral King pendants. Arguments for the Snow Lake pendant appear strongest where there are rare trace-fossils, although the stratigraphy is largely reconstructed due to a series of pre-batholithic faults. The lithologic arguments they offered for other pendants to the south are weakened considerably by the fact that the most intact miogeoclinal-looking pendant in the southern Sierra (Isabella) contains Late Triassic-Early Jurassic fossils within calcareous and quartz-rich strata. Schweickert and Lahren (1991) also proposed detailed correlations of Foothills metamorphic belt terranes and projected terrane boundaries into the southwestern Sierra. These correlations were based on the assumption that all major units and structures of the Foothills belt were continuous at aggregate 500 km-length scales prior to batholith emplacement, and that pre-batholithic structures are well-preserved in the southern Sierra pendants. This reasoning is undermined by the intensity of the tectonic overprint that much of the southern Sierra metamorphic framework experienced during Cretaceous batholith emplacement and intra-batholithic dextral shearing. Nevertheless, some aspects of the correlations proposed by Schweickert and Lahren (1991) are plausible, although the degree of continuity in units and major structures as they show them is questionable.

An important starting point in our terrane analysis is the recognition of a major pre-batholithic tectonic boundary of probable lithosphere scale (CLB) that roughly separates the batholithic domain of Kings sequence pendants from the domain of the El Paso terrane as well as sediment-poor early Mesozoic metavolcanic pendants such as Mount Goddard (modified from Kistler, 1990; Dunne and others, 1991; Dunne and Suczek, 1991; Saleeby and Busby-Spera, 1992). Based on isotopic and trace element concentration data on batholithic rocks Kistler (1990) hypothesized that the CLB separates North American lithosphere from western oceanic ("Panthalassan") lithosphere. The boundary appears to coincide with the Kern Plateau shear zone which was reactivated during the Early to early Middle Jurassic, and which underwent further modest reactivation during the Late Cretaceous (Dunne, 1989; Dunne and others, 1991; Dunne and Saleeby, 1993). Kistler (1990) suggests that the boundary extends northward through the Mineral King and Boyden Cave pendants and connects with the Melones fault, the latter of which implies significant Late Jurassic activity along the boundary. The trace of the CLB in the Mineral King to Boyden Cave region is complicated by Cretaceous dextral offsets, and will be treated below. To the north the boundary does not coincide with the Melones fault because the Melones fault lies totally within the western oceanic lithosphere (Saleeby, 1981; Saleeby and others, 1986; Sharp, 1988). The northern segment of the boundary must thus lie east of the Melones fault within the Foothills belt or, alternatively, it continues as a cryptic feature within the batholith.

Further constraints on the location of the northern segment of the CLB may be provided by considering petrochemical data on the batholith in the context of Kings sequence stratigraphy. Pursuing Kistler's (1990) logic, and the parallel works of Ague and Brimhall (1988a) and Chen and Tilton (1991), the southern Sierra Nevada batholith may be divided into three major longitudinal geochemical domains (Fig. 1a): 1) a western domain with low initial Sr_i and $\delta^{18}O$ values, which coincides with Foothills ophiolite belt exposures and is west of the 0.706 isopleth; 2) a medial domain of high initial Sr_i and high $\delta^{18}O$ values, which lies between the 0.706 line and the CLB; and 3) a high Sr_i and lower $\delta^{18}O$ domain which lies east of the CLB.

The high initial Sr_i-high $\delta^{18}O$ domain has acquired its geochemical distinctiveness for the most part through the melting of, and resulting contamination by, Kings sequence pelite-psammite units. This is most clearly displayed in the southward migmatization of the upper (?) fine turbiditic unit of the Isabella pendant (Saleeby and Busby-Spera, 1986), and the southward partial to complete melt stripping of pelite-psammite units traversed into the deep level exposures of the southernmost batholith (Saleeby and others, 1987; Saleeby, 1990a). Utilizing the Kings sequence facies model of Saleeby and others (1978) and Saleeby and Busby-Spera (1992) the lower Mesozoic basinal turbiditic and olistostromal units, particularly of the more westerly facies, bear the closest resemblance to the western phyllite belt of the Calaveras complex (Schweickert and others, 1977) which corresponds to the eastern Sullivan Creek terrane of Sharp (1988). As generally implied in Kistler's (1990) reconstruction the medial, Kings sequence-contaminated, domain of the batholith projects into these mainly pelitic-psammitic rocks of the Foothills belt. By inference the CLB projects into the area of the Sonora fault or alternatively the Shoo Fly-Calaveras thrust of Schweickert and others (1988).

Following the debates of Schweickert and others (1988) versus Bhattacharyya and Paterson (1984), Tobisch and others (1987), and Sharp (1988), regarding the existence or nature of the Sonora fault, Saleeby and others (1986) and Saleeby and Busby-Spera (1992) interpret the entire western phyllitic unit of the Calaveras complex as a tectonite belt that is itself a distributed ductile thrust zone. Age and structural relations discussed in Sharp (1988) indicate a Middle or possibly Early Jurassic age of deformation along the belt. Structural patterns and kinematic indicators suggest west-directed thrusting with a dextral tangential component. Gradational relationships and reworked chert pebbles suggest that the phyllites rested depositionally above the Calaveras chert unit, analogous to what was discussed for western Kings sequence strata that lie above the Kings-Kaweah ophiolite belt. Furthermore, similar Lower Triassic and Triassic limestones occur in both the phyllitic and chert-argillite units (Bateman and others, 1985). The interpretation offered in Saleeby and others (1986) and Saleeby and Busby-Spera (1992) is that the Calaveras phyllite belt, chert unit and the Shoo Fly complex represent an accretionary prism-like structural sequence with the Shoo Fly-Calaveras thrust having initially formed possibly as early as Triassic time, with subsequent thrust deformation progressing into the phyllite belt forearc rocks through Early(?) and/or Middle Jurassic time. Inasmuch as Calaveras chert is known, at least locally, to sit depositionally on Paleozoic ophiolite (Saleeby, 1990b), actual lithospheric boundary appears more closely related to the Shoo Fly-Calaveras thrust; early Mesozoic thrust motion was probably superposed over an older late Paleozoic tectonic boundary termed the Foothills suture (Saleeby, 1981, 1990b, 1992b). As discussed below, there is also reason to suspect that the Kern Plateau shear zone also underwent significant early Mesozoic remobilization, but that the actual lithospheric boundary is older.

In the next section we present arguments for the CLB having formed originally in late Paleozoic time. The Kern Plateau segment of the boundary records early Mesozoic kinematic indicators that cannot easily account for the fundamental nature of the boundary. The indicators suggest east-side-down vertical displacement which in current attitude is normal in sense (Dunne and others, 1991; Dunne and Saleeby, 1993). Saleeby and Busby-Spera (1992) pose the possibility that the shear zone was subsequently rotated in Late Jurassic or Cretaceous time, and that it originally formed along the footwall of a major east-directed late Early-to-Middle Jurassic thrust system which rooted beneath the Kings sequence to the west. This speculation was devised in order to account for the fundamental nature of the structure in a context that considered well-preserved NE-directed pre-Cretaceous fold and thrust structures within the Kern Canyon pendant (Saleeby, 1992a). An equally, and perhaps more viable interpretation of the Kern Plateau shear zone is that it records a major early Mesozoic extensional overprint on the CLB. This is not only consistent with the available structural data, but its possible northward projection into the Mineral King pendant (Kistler, 1990) may be manifest as the sequence of Late Triassic-Early Jurassic extensional calderas recorded in the Mineral King stratigraphy (Busby-Spera, 1984b; Busby-Spera and Saleeby, 1987). Furthermore, regional relations suggest that the entire early Mesozoic arc to forearc region of the southwest Cordillera formed under conditions of regional extension (Busby-Spera, 1988; Saleeby and Busby-Spera, 1992; Saleeby, 1992b). In Figure 1a we show the CLB as a diffuse belt within the batholith which respects its probable early Mesozoic remobilization and subsequent Cretaceous batholithic overprinting which blurred its trace

Longitudinal Continuity of Tectonic and Stratigraphic Units Along the Strike of the Pre-batholithic Framework

The assumption that lower Paleozoic units of the western Foothills belt and the adjacent Basin and Range and Mojave Desert regions are regionally continuous in the southern Sierra metamorphic framework poses boundary conditions on terrane analysis which probably don't exist. In addition to the disruptive tectonics of Cretaceous batholith emplacement, three major tectonic processes have interacted to almost assure that the southern Sierra pendants will only preserve a very fragmented pre-Mesozoic basement framework. These are: 1) polyphase truncational tectonics; 2) multiple episodes of thrust tectonics with highly divergent transport directions; and 3) early Mesozoic extension in the arc and forearc region.

Numerous workers in U.S. Cordilleran tectonics have argued for a distinct early Mesozoic tectonic truncation event that obliquely cut the Antler and Sonoma deformation belts and their miogeoclinal autochthon along the eastern Sierra region, and that established the generally NW grain of the Sierra Nevada metamorphic framework and batholith (Hamilton and Meyers, 1966; Burchfiel and Davis, 1972; Schweickert, 1976). In contrast Saleeby and Busby-Spera (1992) argue for a polyphase truncation history that had pre-, syn- and post-Sonoman increments, and had multiple opposing senses of displacement. The early phases consisted of late Paleozoic sinistral transform faulting which resulted in the juxtaposition of Paleozoic ophiolitic basement against truncated Antler belt rocks and their miogeoclinal autochthon. We interpret this as the origin of the CLB. Fragments of the Shoo Fly complex were conceivably transported southward along CLB along with the transform ophiolite belt. Other significant sinistral displacements related to this episode of transform faulting probably affected the inner edge of the El Paso terrane (Stone and Stevens, 1988; Walker, 1988), and the Caborca-Hermosillo continental block (Stevens and others, 1992) with the later representing the main block displaced from the continental truncation zone. Magnitude of displacement was on the order of 1000 km. Saleeby and Busby-Spera (1992) and Saleeby (1992b) consider this phase of transform tectonics to have continued through Sonoman time with the southeast transport of Sonoman thrust sheets to the east being tectonically bounded by and working in concert with the sinistral transform system. At the close of Sonoman thrusting and sinistral transform faulting the basement framework for the Kings sequence was established as a regional ophiolitic melange with an eastern selvage of displaced Shoo Fly rocks and possible Antler belt-miogeocline autochthon fragments.

The next phase of the polyphase truncation history was primarily during Jurassic time with initial dextral sense transpression and transtension, and abruptly overprinted Late Jurassic-earliest Cretaceous sinistral transpression and transtension (Saleeby and others, 1986; Oldow and Gerber, 1987; Saleeby and Busby-Spera, 1992; Wolf and Saleeby, 1992; Saleeby and Harper, this volume). Magnitudes of tangential displacement were probably on the order of 100 km.

The final phase of the polyphase truncation history was during middle to Late Cretaceous batholithic activity (Saleeby, 1981, 1991; Lahren and others, 1990; Kistler, this volume). As discussed above, the right-stepping pattern of grossly coeval pluton emplacement loci in conjunction with syn- and immediately post-batholithic dextral ductile shear zones (Figs. 1a and b) suggests significant dextral displacement of metamorphic framework rocks during Cretaceous batholith emplacement. Magnitude of displacement was again on the order of 100 km.

Throughgoing structures are very difficult to delineate for any given phase of the polyphase truncation history. It is important to recognize that the net result has been an intense shuffling of basement terranes along the axis of the southern Sierra Nevada with minimum dispersion limits probably represented to the north by the tip of the promontory of high initial Sr_i plutons shown in Kistler (1990 and this volume) and to the south by the Coborca-Hermosillo block (Stevens and others, 1992). Furthermore, as shuffling progressed the crustal blocks being shuffled became progressively sub-horizontally tectonically interlayered by multiple thrusting events and possible low-angle extensional faulting phases.

Two points are worth exploring in regard to low-angle tectonic layering of crustal slivers. 1) First, there is a tendency to draw terrane boundaries through the southern Sierra generally parallel to the NW structure of the batholith, its pendants and the western Foothills belt (Nokleberg, 1983; Schweickert and Lahren, 1991). This may be highly erroneous if earlier thrust systems extended into the metamorphic framework, particularly at high angles to the NW grain. In particular, it is reasonable to assume that the El Paso terrane sits tectonically above miogeoclinal strata along NE-trending Antler and/or Sonoman thrust faults as well as NW trending thrusts of the eastern Sierra system. Lahren and others (1990) and Schweickert and Lahren (1991) group the Snow Lake, Dinkey Creek and Boyden Cave pendants into one continuous longitudinal terrane (Snow Lake block). We accept the likelihood of miogeoclinal basement within these pendants. However, the early Mesozoic geologic histories are drastically different, at least between Boyden Cave and Snow Lake. For example, late Jurassic dikes and plutonic rocks cut the Snow Lake pendant, but are lacking both in the Boyden Cave and Dinkey Creek pendants. Furthermore, the presumed lower Mesozoic overlap strata at Snow Lake is shallow water in nature, whereas Boyden Cave and possibly Dinkey Creek preserve an abundance of overlapping marine basinal strata. It follows that different fragments of the aerially extensive miogeocline section may be represented in the Boyden Cave and Dinkey Creek versus Snow Lake pendants, having been derived from fundamentally different structural settings. Second, there is abundant stratigraphic and petrotectonic evidence that the early Mesozoic arc and forearc regions of the southwest Cordillera were under regional extension during formative stages (Busby-Spera, 1988; Saleeby, 1990b, 1992b; Saleeby and Busby-Spera, 1992). As discussed above, the Kern Plateau shear zone in present attitude records apparent large magnitude east-side-down normal-sense displacement in early Mesozoic time. Small pendants of quartz-rich tectonites occur immediately west of the shear zone in the Durrwood Meadows area (Fig. 1a and b). These are presumed to be Kings sequence or miogeoclinal basement fragments. It is not unlikely that fragments of lower plate miogeoclinal rocks, such as those possibly of the Durrwood Meadows area, were pulled out from beneath the El Paso terrane by early Mesozoic extensional faulting, and thereby delivered into the Kings sequence basement regime. Such a displacement pattern would conceivably blur the CLB as well.

In summary, the sense that terrane boundaries in the southern Sierra should be longitudinally oriented, generally steep structures is an artifact of polyphase strike-slip truncations through the region, and the strong syn-batholithic overprint which imparted generally longitudinal metamorphic tectonite fabrics and the emplacement of grossly concordant elongate plutons. It is more realistic to view the southern Sierra pre-Mesozoic framework as a highly shredded, mainly Paleozoic basement melange consisting of the western Foothills ophiolite belt, an eastern selvage of displaced Shoo Fly complex, and possible fragments of miogeoclinal and Antler belt rocks. This basement complex was juxtaposed against an eastern buttress of Antler belt rocks (El Paso terrane) together with its miogeoclinal autochthon. Arc and forearc strata of the Kings sequence formed across the western zone of this basement complex which possibly underwent extensional faulting during Kings sequence deposition.

<u>Extent and Destruction of Kings Sequence Basinal System</u>

Saleeby and others (1978) considered the Kings sequence to consist of two major facies: 1) an eastern facies characterized by shallow water carbonates and quartz rich detrital rocks, with variable amounts of silicic volcanic material, which became basinal in Early Jurassic time; and 2) a western facies of basinal character, typified by abundant pelite, mixed quartzose and volcaniclastic turbidites and olistostromes interfingering westward with forearc mafic volcanic rocks and chert-argillite that are deposited above the Foothills ophiolite belt. We assert that this general facies model is still applicable, but we now have better constraints on some of the basement relations and on the distribution of volcanic-rich strata. With a more thorough understanding of the actual distribution of mid-Cretaceous versus early Mesozoic metavolcanic rocks in the southern Sierra, we now recognize a more restricted distribution of early Mesozoic volcanic units. Furthermore, restrictions on the dispersal of early Mesozoic volcanic and volcaniclastic units were imposed by large caldera structures and a regional easterly arc graben system, as represented by rocks of the Mineral King pendant (Busby-Spera, 1988).

Throughout a number of the more easterly Kings sequence pendants thick marble and calcsilicate rock units with metaquartzite pebble grits and conglomerates lie between basinal-facies turbidite sections and more varied and possibly structurally complex quartzite-rich assemblages. Examples include the Boyden Cave, Sequoia, Kern Canyon, and upper Tule River pendants. We interpret the intervening rocks as an extensive Triassic overlap sequence with major carbonate deposition culminating in Carnian-Norian time. The overlap sequence capped a structurally complex basement collage that was assembled by transpressive deformation along the truncated edge of the Sonoman deformation belt and its Antler belt-miogeocline autochthon. The overlap sequence is considered to be broadly analogous to the Bond Buyer Formation of the El Paso Mountains (Walker, 1988), the Fairview Valley Formation of the southwest Mojave (Miller and Cameron, 1982), and Moenkopi equivalent strata of the Inyo Mountains and eastern Mojave region (Walker and others, 1983). In the southern Sierra Nevada region a broad carbonate platform formed by Carnian-Norian time with local centers of silicic volcanism marking arc activity. In Early Jurassic time much of the region subsided due to regional extension (Busby-Spera, 1988; Saleeby, 1992b) and became basinal. Discrete centers of silicic volcanism continued to be active as recorded at Mineral King. Mafic lava and pyroclastic flows erupted sporadically over the forearc region.

As discussed above, basinal turbiditic strata of the Kings sequence extend westward onto the Foothills ophiolite belt and are intercalated with the forearc mafic volcanic rocks. These strata are directly analogous to the western phyllite belt of the Calaveras complex and their intercalated mafic volcanic rocks (Sullivan Creek or Don Pedro terrane; Schweickert and others, 1977; Saleeby and others, 1986; Sharp, 1988). These strata as well as chert-rich Calaveras strata are in thrust sequence below the Shoo Fly complex. Further north broadly analogous strata of the Sailor Canyon Formation lie in depositional contact above the Shoo Fly complex. The Lower to Middle Jurassic Sailor Canyon Formation is in large part a forearc to intra-arc basinal sequence with quartz arenites that lies depositionally above Carnian-Norian limestone, which in turn lies unconformably above a Permian arc sequence built on the Shoo Fly complex (McMath, 1966; Harwood, 1988). The Carnian-Norian carbonates are here considered to be part of the regional post-Sonoman overlap sequence that, as in the southern Sierra region, was followed by basinal conditions reflecting regional extension (Fisher, 1990). These regional relations suggest that the Lower Jurassic Kings sequence, the western phyllite belt strata of the Calaveras complex and the Lower Jurassic basinal strata of the Sailor Canyon Formation were parts of a large forearc to intra-arc basin system that was built above the western truncated edge of the Sonoman deformation belt, including the Shoo Fly complex, and across the juxtaposed Foothills ophiolite belt. This basinal system was telescoped and thereby destroyed during Middle and Late Jurassic regional thrusting (Saleeby, 1981; Schweickert, 1981; Sharp, 1988).

Cretaceous Dextral Displacement Along the Sierra Nevada

Dextral displacements of Cretaceous age along the Sierra Nevada are clearly demonstrated for the proto-Kern Canyon and Rosy Finch shear zones (Fig. 5) (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1989; Tikoff and Teyssier, 1992; Saleeby, 1992a). Furthermore, large magnitudes of dextral displacement may be envisaged if motion was coupled to batholith pluton emplacement (Saleeby, 1991). Critical problems to be addressed are: 1) how these and additional dextral displacements may relate to the northward projecting promontory in high initial $^{87}Sr/^{86}Sr$ plutons; 2) how the Snow Lake pendant arrived at its current position; 3) how large and coherent the Snow Lake block was; and 4) what the overall implications are for the southern Sierra pre-batholithic framework.

Lahren and others (1990) and Schweickert and Lahren (1991) suggest that the Snow Lake pendant was transported ~400 km northward from the western Mojave region as a ~ 200 km long crustal sliver along the Mojave-Snow Lake fault. The proposed fault has been totally obliterated by the batholith in the Sierra Nevada and Mojave Desert; however, the proposed trace of the Snow Lake fault cuts obliquely across the fundamental petrochemical structure of the batholith. It thus seems unlikely that the Snow Lake block existed as an intact crustal block. As mentioned above, of the three definitive pendants of the "Snow Lake block", the Snow Lake pendant has an early Mesozoic geologic history distinct from that of the Dinkey Creek and Boyden Cave pendants, and thus there is no reason to tie all of them together as a coherent crustal block in Mesozoic time. Their connection as a pre-batholithic coherent crustal block derived from the western Mojave region is not supported by isotopic data on the proximal batholithic rocks, as proposed by Lahren and others. Initial Sr_i values on the batholithic rocks in the region of the Snow Lake pendant range from 0.706 to 0.7065 and $\delta^{18}O$ values are typically < 9 $^0/_{00}$ (Kistler and Peterman, 1973, 1978; Kistler, 1990). In contrast, western Mojave region values are typically 0.709 to 0.711 and > 9 $^0/_{00}$ (Kistler, 1990; written commun., 1993). These are very large differences that are difficult to account for if the Snow Lake pendant was attached to a coherent crustal block derived from the western Mojave region.

A synthesis of isotopic and age data on Mesozoic plutonic and volcanic rocks of the Sierra Nevada region indicates Early to middle Cretaceous dextral displacements of ~100 km on both the AIB and EIB (Fig. 1a; Kistler, this volume). These displacements only account for one-half of the displacement proposed for the Snow Lake pendant by Lahren and others (1990), but they do return the Snow Lake rocks to a position that could satisfy the hard constraints.

Correlation of the Snow Lake pendant rocks with miogeoclinal rocks of the western Mojave Desert is based on lithologic similarities of the metasedimentary sequences with the added constraints of the ~148 Ma Independence dikes occurring in both, along with Late Jurassic felsic to mafic plutons, and the occurrence of Fairview Valley-like lower Mesozoic strata as an unconformable overlap on the Snow Lake Paleozoic strata (Lahren and others, 1990). These authors reconstruct the bounds of the Death Valley facies (after Stewart, 1970) in such a way as to make an apparent piercing point with the Independence dike swarm in the western Mojave. The reconstruction has considerable uncertainty, however, and the possible bounds on this uncertainty are shown in Figure 1a. Using the Figure 1a constraint, the Snow Lake pendant could have moved on the order of ~200 km along the axial and eastern Sierra region from the region west of the Inyo Mountains and the Coso and northern Argus Ranges. There are abundant Independence dikes in the region (Chen and Moore, 1979) and Death Valley facies strata not only project into the region, but upper stratigraphic levels of the miogeoclinal rocks are abundant as pendants in Jurassic and Cretaceous plutons of the region (Dunne and others, 1978). Furthermore, Death Valley facies rocks are likely to have extended even farther to the northwest beneath Inyo facies miogeoclinal rocks along the Last Chance thrust system (Snow, 1992). This expanded region contains abundant Independence dikes as well, although derivation of the Snow Lake rocks from such lower plate rocks would require an early phase of deep unroofing for a western, now obliterated, segment of the thrust system. Considering the derivation of the Snow Lake rocks from a region west of the Inyo Mountains to the northern Argus Range region, the Snow Lake lower Mesozoic overlap strata could be Moenkopi-equivalent as in the Inyo Mountains (Walker and others, 1983). Furthermore, Late Jurassic plutons of mafic to felsic composition are widespread along the Inyo, Argus and Coso Ranges as well as along the adjacent eastern Sierra region (Evernden and Kistler, 1970; Dunne and others, 1978, 1991; Chen and Moore, 1982; Dunne and Saleeby, 1993), satisfying the final constraint.

Consideration of the southern extensions of the EIB and AIB raises a number of interesting issues. Displacement along EIB would presumably have affected El Paso terrane rocks of the Kern Plateau region as well. Such displacement could diminish considerably, however, if the Cretaceous plutons emplaced between Snow Lake and the Kern Plateau regions accommodated a component of overall dextral displacement (cf. Saleeby, 1991). Note that on Figure 1a a major lobe of the Late Cretaceous batholith truncates the northern terminus of Jurassic and older rocks of the Kern Plateau region. The right stepping pattern in the Cretaceous batholith created by this lobe may have corresponded to a synbatholithic breakaway zone in the pre-Cretaceous framework. Thus displacement along EIB may not have extended in its entirety into the El Paso Mountains-northern Mojave Desert region while displacing the Snow Lake pendant rocks ~100 km.

The southern trace of the AIB raises a number of questions. Kistler (this volume) uses the mid-Cretaceous metavolcanic rocks of the Boyden Cave pendant as a piercing point, and correspondingly runs the AIB through the Boyden Cave pendant in the location of the early syn-batholithic fault and adjacent deformed mid-Cretaceous intrusions (Fig. 4). He extends the AIB southward through the Farewell fault of the Mineral King pendant (Fig. 2). This fault cannot accommodate ~100 km of displacement, however. Possible locations in this region are to the east of Mineral King, but for the most part cut out by the ~97 Ma Granite of Coyote Pass (Busby-Spera, 1983) which is partly sheared along the syn-to-late magmatic dextral Coyote Peaks fault (Moore and Sisson, 1985); and/or to the west of Mineral King through the zone of mid-Cretaceous metavolcanic pendants (Fig. 1b). Right lateral shearing of the Mineral King pendant adjacent to AIB is perhaps manifest by the Farewell and possibly Empire faults (Fig. 2). Farther to the south AIB may correspond to an early offset phase along the proto-Kern Canyon fault zone. We have noted that a steep-tectonically active buttress unconformity in a thick mid-Cretaceous ash flow sequence preserved in the Erskine Canyon area of the fault zone south of Lake Isabella could record a mid-Cretaceous phase of activity along the fault zone (Saleeby and Busby-Spera, 1986). An additional attractive aspect of significant AIB displacement along the proto-Kern Canyon fault zone is that the Sequoia Park pendant would restore to close proximity of the Isabella pendant; as discussed above, these two pendants have very similar sequences. Furthermore, the Kern Canyon pendant has a number of differences with the juxtaposed Isabella pendant (Fig. 3), and an additional early phase of movement along the fault zone would help account for these. Late-phase (85 to 90 Ma) movement along the fault zone is constrained to be up to ~15 km (Moore and DuBray, 1978; Ross, 1986), but this value is based on offset markers along late-stage brittle-fault sets of the system which may not correspond to the main structure in the north, and does correspond to the main structure in the south (Fig. 1b).

An additional possible trace, or branch, of AIB conceivably ran along the belt of highly deformed and intruded small pendants of the Durrwood Meadows area (Fig. 1a and b). In this case, much of the structure would be cut out by 85 to 90 Ma batholithic rocks of the area, which were also syn-magmatically sheared along their western borders by the proto-Kern Canyon fault zone (Saleeby and Busby-Spera, 1986; Busby-Spera and Saleeby, 1990; Ross, 1990; Saleeby, 1992a). Possibly AIB displacement was partitioned into both the proto-Kern Canyon and Durrwood Meadows zones as well as in local late-stage reactivation of the Kern Plateau shear zone (Dunne and Saleeby, 1993). The small pendants of the Durrwood Meadows area consist primarily of quartz-rich metamorphic tectonites which could be fragments of miogeoclinal and/or lower Mesozoic Kings sequence rocks that were juxtaposed against El Paso terrane rocks to the east along AIB. Alternatively, as discussed earlier the Durrwood Meadows metasedimentary rocks could represent lower plate miogeoclinal rocks that were exhumed from beneath the El Paso terrane during early Mesozoic extensional remobilization of the Kern Plateau shear zone.

We close on an issue that is relevant to the final point raised above as well as the implications of Kistler's (this volume) reconstruction of the AIB and EIB offsets.

Restoration of the AIB offset, as outlined above, places the Boyden Cave and Dinkey Creek pendants in close proximity to the Kern Plateau shear zone. We raise the question as to whether possible miogeoclinal basement fragments for these pendants were pulled out from beneath the El Paso terrane during early Mesozoic regional extension, and subsequently overlapped by Kings sequence marine strata. In contrast, the miogeoclinal basement rocks of the Snow Lake pendant resided in a position farther to the north where they were overlapped by Moenkopi equivalent strata following post-Sonoman unroofing and then were subsequently cut by the eastern Sierra region belt of Jurassic plutons and the Independence dikes.

SUMMARY

We have presented stratigraphic relations for the relatively well-preserved lower Mesozoic stratified rocks of the southern Sierra Nevada which are in general support of our 1978 synthesis. As pointed out by Schweickert and Lahren (1991), however, we now recognize the likelihood of Paleozoic quartz-rich detrital rocks in some or many of the Kings sequence pendants. Such rocks are more likely to be disparate fragments of a highly dismembered polygenetic basement composed of Paleozoic ophiolitic, Shoo Fly, miogeoclinal and possibly Antler belt rocks rather than coherent terranes or crustal blocks. Dismemberment and reassembly of the basement complex involved transform truncation tectonics and Foothills ophiolite belt emplacement prior to and coincident with Sonoman thrust tectonics. The base of the lower Mesozoic Kings sequence may have formed part of a regional post-Sonoman (Triassic) marine overlap sequence above this basement complex. Additional complexities in the basement complex may have developed during early Mesozoic extensional tectonism. Following the establishment of a Carnian-Norian carbonate platform, as part of the overlap sequence, the region subsided and became part of a regional Early Jurassic extensional forearc and intra-arc basin system. The basinal system was destroyed by Middle to Late Jurassic thrusting.

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